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GaAs ANALOG INTEGRATED CIRCUITS (GaAs RF-LSI)

PHASE I PROGRESS REPORT

VOLUME II. APPENDICES

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August 1979

Contract No. N00039-78-C-0305

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APPENDIX A
DERIVATION OF FET MODELING CODE

1.1 INTRODUCTION

The TRW FET model is biased on a two region approximation to the conditions under the gate. The following sections derive the noise figure from this assumption. Section 5 indicates how a variable vertical doping profile is included in the model and Section 6 describes how the parasitic resistances and capacitances are calculated.

2. THE INTRINSIC FET

2.1 THE FET MODEL

One of the many FET models that have been developed in the last decade, with the fewest restrictions and assumptions, is the Grebene-Ghandi model. Its fundamental principle is a two-piece linear approximation of the velocity-field characteristic of a semiconductor exhibiting velocity saturation as shown in Figure 2-1.

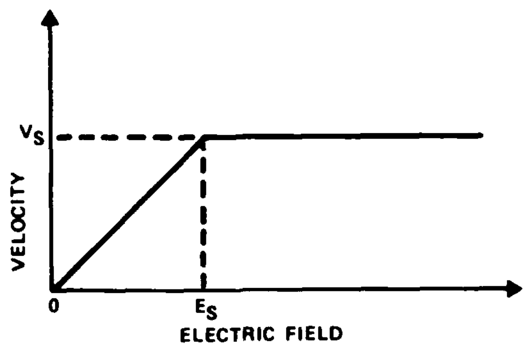
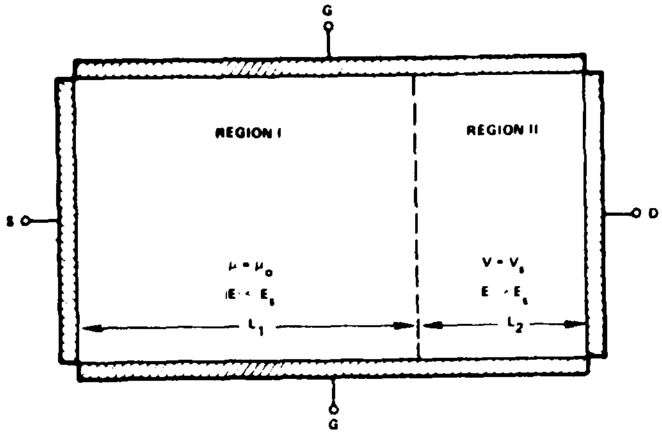


Figure 2-1. Two-Piece Linear Approximation of the Velocity-Field Characteristic of a Semiconductor Exhibiting Velocity Saturation

This velocity-field characteristic divides the intrinsic FET model into two regions: region I of length L_1 the constant mobility region where the velocity is field-dependent; and region II of length L_2 the constant velocity region where the electric field has exceeded the critical field E_s and the carriers travel at the saturation velocity V_s independent of field strength. This two-region model for the intrinsic FET is shown in Figure 2-2. The piecewise linear approximation of the velocity-field characteristic necessarily involves compromise in the choice of values used of E_s, μ_0, and V_s. The mobility (μ_0) is evaluated from the doping density (N_0) by the use of a Taylor Series expansion as

$$\hat{\mu_0} = 10^{[-2.751 \times 10^{-3} \times \log^3(N_0) + 1.0249 \times 10^{-1} \times \log^2(N_0) - 1.251 \times \log(N_0) + 8.8249]} \quad (2\text{-}1)$$



REGION I: CONSTANT MOBILITY REGION, FIELD DEPENDENT VELOCITY
REGION II: CONSTANT VELOCITY REGION, FIELD INDEPENDENT VELOCITY

Figure 2-2. Two Section Model of the FET

Equation (2-1) is in essence the result of curve fitting techniques applied to the velocity - doping characteristic for type GaAs as given by Sze[1] in the range $10^{14} < N_0 < 10^{18}$

For a typical mobility value of μ_0 = 4500cm/Volt-sec E_s needs to be chosen as 2.9 kV/cm in order to obtain the typical saturation velocity of

$$V_s = \mu_0 E_s = (4500 \text{ cm}^2/\text{v-sec})\ (2.9 \text{ kV/cm}) = 1.3 \times 10^7 \text{ cm/sec.}$$

This choice for E_s is somewhat lower than the measured saturation field

$$3 \text{ kV/cm} < E_s < 4 \text{ kV/cm;}$$

however, it is the only compromise made throughout the model, and the choice is certainly justifiable on the basis of good correlation between thoretical and experimental data of noise, dc conditions, and small signal parameters.

2.2 SMALL SIGNAL PARAMETERS

The FET model outlined in Section 2-1 has an equivalent circuit as shown in Figure 2-3.

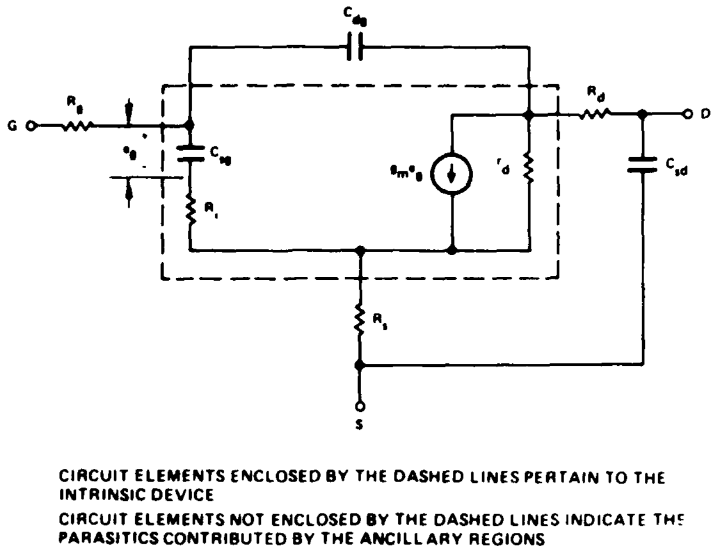


Figure 2-3. Small Signal Equivalent Circuit of the FET

The circuit elements enclosed by the dashed line constitute the intrinsic FET (region under the gate) and elements outside the dashed line are the parameters contributed by the ancillary regions. A prospective sketch of the FET indicating the geometric regions responsible for each circuit element is shown in Figure 2-4. Each of these circuit elements can be expressed as a function of the characteristic dimensions of the device, corresponding doping concentration of the region under consideration, and the dc biasing conditions.

Figure 2-5 is a cross-sectional diagram of the intrinsic FET showing various geometrical dimensions and potentials used in the equations to follow. From Figure 2-5 by adding potential drops inside the FET (i.e., in the channel and depletion region) and equating this sum to the externally applied voltages the following equations result:

$$V_{sg} = W(x) - \phi + V(x)$$

or

$$W(x) = V_{sg} + \phi - V(x) \qquad (2\text{-}2)$$

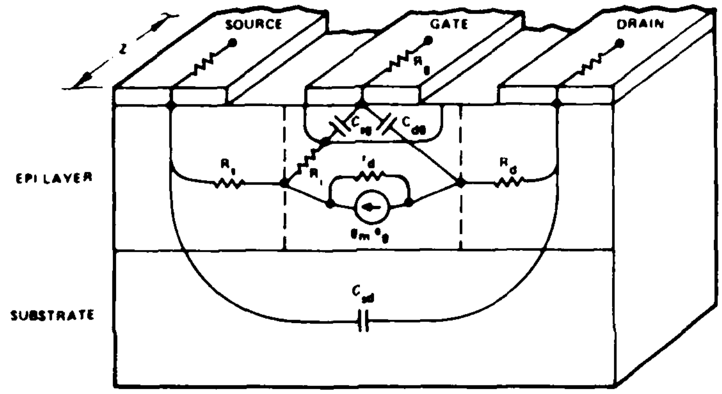


Figure 2-4. Perspective Sketch of the FET Indicating Geometric Regions Responsible for each Equivalent Circuit Element

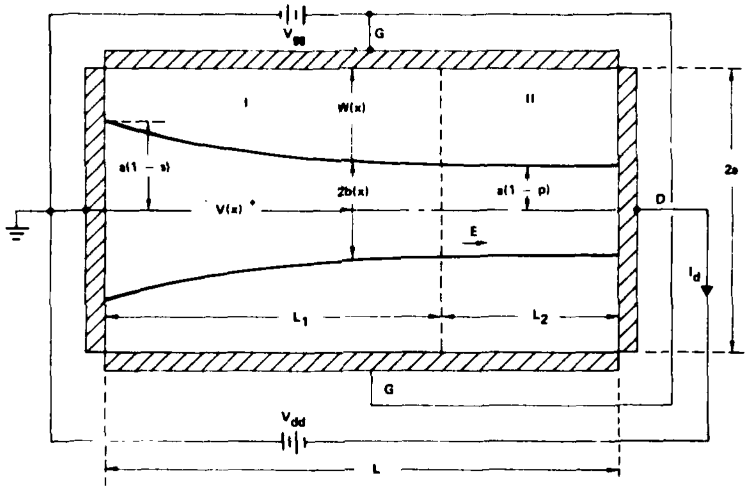


Figure 2-5. Cross-Sectional Diagram of the Idealized FET showing Geometrical Dimensions and Potentials

Here $V(x)$ is the potential at position x in the channel with respect to the source while $W(x)$ is the potential in the channel with respect to the gate. In particular, $W(x)$ is the potential drop across the depletion region. It does not include the built-in potential of the gate, ϕ. Therefore, ϕ adds to the gate bias, V_{sg} and is typically

$$0.6 \text{ volt} \leq \phi \leq 0.7 \text{ volt}$$

for GaAs Schottky barrier junction using aluminum metallization. At the source $(x = 0)$, $V(0) = 0$, and equation 2-2 becomes

$$W(0) \equiv W_s = V_{sg} + \phi$$

At the interface of regions I and II, $(x = L_1)$, $V(L_1) \equiv V_p$, and equation (2-2) becomes

$$W(L_1) \equiv W_p = V_{sg} + \phi - V_p \tag{2-4}$$

at the drain $(x=L)$, $V(L) = V_{sd}$, and equation (2-2) becomes

$$W(L) \equiv W_d = V_{sg} + \quad - V_{sd} \tag{2-5}$$

The gate-to-channel potential required to totally deplete the channel of carriers is given by the expression [2]

$$W_{oo} = \left(\frac{qN_o}{2\varepsilon_r\varepsilon_o}\right)a^2 \tag{2-6}$$

where $q = 1.6 \times 10^{-19}$ coulombs, N_o = doping concentration in the channel, $\varepsilon_r = 12.5$ is the relative dielectric constant of GaAs, $\varepsilon_o = 8.854 \times 10^{-14}$ farads/cm is the permittivity of free space, and 'a' is the half-thickness of the semiconductor between the gate electrodes (see Figure 2-5). Since equations (2-3), (2-4), and (2-5) are simply the potential of the depleted region at three different points along the channel, they can be written in the form of equation (2-6) as

$$W_s = \left(\frac{qN_o}{2\varepsilon_r\varepsilon_o}\right)(sa)^2 = W_{oo}s^2 \tag{2-7}$$

$$W_p = \left(\frac{qN_o}{2\varepsilon_r\varepsilon_o}\right)(pa)^2 = W_{oo}p^2 \tag{2-8}$$

$$W_d = \left(\frac{qN_o}{2\varepsilon_r\varepsilon_o}\right)(da)^2 = W_{oo}d^2 \tag{2-9}$$

From equations (2-6), (2-7), and (2-8) "s" and "p" can be expressed as

$$s = (W_s/W_{oo})^{1/2} \tag{2-10}$$

$$p = (W_p/W_{oo})^{1/2} \tag{2-11}$$

The quantities s, p, and d are reduced or normalized potentials. The following analysis will derive the characteristics of the FET in terms of and p.

The potential across the depletion region can be found by assuming that the potential changes in the y direction much more rapidly than in the x direction. That is

$$\frac{\partial W(x)}{\partial y} \gg \frac{\partial V(x)}{\partial x}$$

This condition is satisfied when the channel thickness, a, is much smaller than the channel length, L. Making this assumption allows one to calculate the y component of the electric field using Gauss' law. Integrating a second time gives the potential W(x). Since there are no surface charges along the edges of the depletion region, the potential is

$$\begin{aligned} W(x) &= \left(\frac{qN_o}{2\varepsilon_r\varepsilon_o}\right)[a - b(x)]^2 \qquad (2\text{-}12) \\ &= \left(\frac{qN_o}{2\varepsilon_r\varepsilon_o}\right)a^2[1 - b(x)/a]^2 \\ &= W_{oo}[1 - b(x)/a]^2 \end{aligned}$$

where b(x) is half the channel opening at point x (see Figure 2-5), and (1 - b(x)/a) is the fractional depth of the depletion region at the same point. It is convenient to define this fractional depth as

$$w(x) = 1 - b(x)/a \tag{2-13}$$

Then equation (2-12) can be written as

$$W(x) = W_{oo}[w(x)]^2 \tag{2-14}$$

Comparing equation (2-14) to (2-7) and (2-8) indicates that s and p correspond to w(x). Therefore, s and p not only represent reduced potentials but are also related to the depth of the depletion region. In Figure 2-5, (1-s) and (1-p) are accordingly

indicated as the fractional channel openings at the source end and in region II, respectively. The drain current at point x is given by Ohm's law as

$$I_d = 2b(x)\ Z\sigma\ [\partial W(x)/\partial x] \qquad (2\text{-}15)$$

where Z is the gate width,

$$\sigma = q\mu_o N_o$$

the conductivity of the undepleted region of the channel and $\partial W(x)/\partial x = E_x(x)$ the longitudinal field in the channel at point x. From equation (2-14) the expression for the longitudinal field can be written in terms of the fractional channel opening as

$$\frac{\partial W(x)}{\partial x} = 2W_{oo}\ w(x)\ \frac{dw(x)}{dx} \qquad (2\text{-}16)$$

From equation (2-13) the expression for the half-channel opening can be obtained as

$$b(x) = a[1-w(x)] \qquad (2\text{-}17)$$

By the use of equation (2-16) and (2-17) equation (2-15) can be written as

$$I_d dx = 4a\sigma ZW_{oo}[1 - w(x)]w(x)dw(x) \qquad (2\text{-}18)$$

Both sides of equation (2-18) can be integrated for region I in which the limits of integration for x are 0 and L_1, and the limits for w(x) are s and p (see Figure 2-5). The result of this integration yields

$$I_d = \frac{2a\sigma ZW_{oo}}{L_1} f_1(s,p) \qquad (2\text{-}19)$$

where

$$f_1(s,p) = p^2 - s^2 - \frac{2}{3}(p^3 - s^3) \qquad (2\text{-}20)$$

In region II the carriers travel at their saturation velocity given by

$$V_s = \mu_o\ E_s \qquad (2\text{-}21)$$

where E_s is the critical longitudinal electric field at which the carriers reach their saturation velocity. Also in region II (or the constant velocity region) half the channel opening is given by

$$b = a(1-p) \qquad (2\text{-}22)$$

and remains constant for $L_1 < x < L$, thus the expression for the drain current in this region is

$$I_d = 2b\sigma ZE_s \tag{2-23}$$

or by equation (2-22), equation (2-23) can be rewritten as

$$I_d = 2a\sigma ZE_s(1 - p) \tag{2-24}$$

Since there is current continuity across the interface of regions I and II, an expression for L_1 can be obtained from equations (2-19) and (2-24)

$$L_1 = \frac{W_{oo}}{E_s}\left[\frac{f_1(s,p)}{(1 - p)}\right] \tag{2-25}$$

Both the drain current and the length of region I are now expressed in terms of s and p. To determine the values of these parameters it also is necessary to express V_{sd} in terms of the reduced potentials.

The source-to-drain potential drop in the channel can be calculated by integrating the longitudinal electric field from x = 0 to x = L; this integration is done in two parts: from x = 0 to L_1 (region I) and from x = L_1 to x = L (region II). For region I the longitudinal electric field is given by equation (2-16)

Thus
$$\int_0^{L_1} \frac{\partial W(x)dx}{\partial x} = 2W_{oo}\int_0^{L_1} w(x)\left[\frac{dw(x)}{dx}\right]dx \tag{2-26}$$

which yields

$$W(L_1) - W(0) = W_{oo}\left[w^2(L_1) - w^2(0)\right] \tag{2-27}$$

From equation (2-13) the fractional depth of the depletion layer can be obtained as

$$w(L_1) = 1 - b(L_1)/a = p \tag{2-28}$$

$$w(0) = 1 - b(0)/a = s \tag{2-29}$$

Substitution of equation (2-28) and (2-29) on the right-hand side of equation (2-27) and substitution of equation (2-3) and (2-4) on the left-hand side of (2-27) gives

$$-V_p = Woo\ (p^2 - s^2) \tag{2-30}$$

For region II the longitudinal electric field is determined entirely by free charges on the drain electrode (neglecting carrier accumulation). In this region the potential satisfies the two-dimensional Laplace's equation

$$\nabla^2\phi = 0 \tag{2-31}$$

For the asymmetrical transistor the boundary conditions for equation (2-31) are:

$$\begin{aligned}
&\frac{\partial\phi}{\partial y}(x,0) = 0 && L_1 < x < L \\
&\phi(x,a) = 0 && L_1 < x < L \\
&\phi(L_1,y) = 0 && -0 < y < a \\
&\frac{\partial\phi}{\partial y}(L_1,y) = E_s && -0 < y < a
\end{aligned} \tag{2-32}$$

Equations (2-31) and (2-32) form a well-formulated boundary-value problem; the solution to this problem is

$$\phi(x,y) = \sum_{n=o}^{\infty} A_n \cos\left[\frac{(2n+1)}{2a}\pi y\right] \sinh\left[\frac{(2n+1)}{2a}\pi(x - L_1)\right] \tag{2-33}$$

which can be truncated to

$$\phi(x,y) \simeq -\frac{2a}{\pi} E_s \cos\left(\frac{\pi y}{2a}\right) \sinh\left[\frac{\pi(x - L_1)}{2a}\right] \tag{2-34}$$

in which only the first term is considered. This approximation removes the terms with large arguments in the exponentials of the hyperbolic sine term which vary rapidly with y. The voltage across region II is therefore

$$\phi(L,0) - \phi(L_1,0) = -\frac{2a}{\pi} E_s \sinh\left[\frac{\pi(L - L_1)}{2a}\right] \tag{2-35}$$

where $\phi(L_1,0) = 0$ due to the boundary conditions given by equation (2-32). The overall source-to-drain potential drop in the channel is finally obtained from equations (2-30) and (2-35) as

$$\begin{aligned}
V_{sd} &= W_{oo}\left\{(p^2 - s^2) + \frac{2a}{\pi}\left(\frac{E_s}{W_{oo}}\right) \sinh\left[\frac{\pi(L - L_1)}{2a}\right]\right\} \\
&= W_{oo}\left\{(p^2 - s^2) + \frac{2}{\pi}\left(\frac{a}{L}\right) \xi \sinh\left[\frac{\pi(L - L_1)}{2a}\right]\right\}
\end{aligned} \tag{2-36}$$

where

$$\xi = \frac{E_s L}{W_{oo}} \tag{2-37}$$

Equations (2-3) and (2-7) relate s to the gate voltage. After substituting for L_1, equation (2-36) relates s and p to V_{sd}. Therefore, given the bias conditions and the physical properties of the FET, the reduced potentials s and p may be found. Although these equations have been derived for the intrinsic FET, they are still useful when parasitic resistances in the source and drain region of a practical device are included. These parasitics introduce additional voltage drops which are expressed as a parasitic resistance times the drain current. However, using (2-24) for the drain current, one can still reduce the problem to two equations in the unknowns s and p. The following sections will derive additional device parameters and ultimately the minimum noise figure in terms of s and p.

2.2.1 Transconductance

The transconductance of a FET device is defined as

$$g_m = - \left.\frac{dI_d}{dV_{sg}}\right|_{V_{sd} = \text{constant}} \tag{2-38}$$

From equations (2-27) and (2-38) the transconductance can be expressed alternately as

$$g_m = - \frac{\partial I_d}{\partial p} \frac{\partial p}{\partial V_{sg}} = 2a\sigma ZE_s\left(\frac{\partial s}{\partial V_{sg}}\right) \tag{2-39}$$

$$= 2a\sigma\, ZE_s \left(\frac{\partial p}{\partial s}\right)\left(\frac{\partial s}{\partial V_{sg}}\right)$$

From equations (2-3) and (2-7) $\partial s/\partial V_{sg}$ can be obtained as

$$\frac{\partial s}{\partial V_{sg}} = \frac{1}{2sW_{oo}} \tag{2-40}$$

Also from equation (2-36) since $dV_{sd} = 0$

$$2pdp - 2sds - \frac{\xi}{L} \cosh \left[\frac{\pi(1 - L_1)}{2a}\right] dL_1 = 0 \tag{2-41}$$

Also from equation (2-25)

$$dL_1 = \frac{W_{oo}}{E_s}\left\{\left[2p + \frac{E_s}{W_{oo}}\left(\frac{L_1}{1 - p}\right)\right]dp - 2s\,\frac{1 - s}{1 - p}\; ds\right\} \tag{2-42}$$

Substituting (2-42) into (2-41) and collecting terms, the ratio dp/ds can be obtained as

$$\frac{dp}{ds} = \frac{2s(1 - s) \cosh [\pi(L - L_1)/2a] - 2s(1 - p)}{[2p(1 - p) + E_s L_1/W_{oo}] \cosh [\pi(1 - L_1)/2a] - 2p(1 - p)} \tag{2-43}$$

Substitution of equations (2-40) and (2-43) into equation (2-39) yields for the trandsconductance

$$g_m = \frac{I_s}{W_{oo}} \left\{ \frac{(1 - s) \cosh [L - L_1)/2a] - (1 - p)}{[2p(1 - p) + \xi L_1/L] \cosh [\pi(L - L_1)/2a] - 2p(1 - p)} \right\} \tag{2-44}$$

$$= \frac{I_s}{W_{oo}} f_g(s,p)$$

where

$$I_s = 2a\sigma Z E_s$$

$$f_g(s,p) = \frac{(1 - s) \cosh [\pi L_2/2a] - (1 - p)}{[2p(1 - p) + \xi L_1/L] \cosh [\pi L_2/2a] - 2p(1 - p)} \tag{2-45}$$

The quantity I_s is the saturation current and represents the maximum current that could flow through the channel assuming no depleted region. Notice that the transconductance function, f_g, is only a function of s and p since $L_2 = L - L_1$, and equation 2-25 defines L_1 in terms of s and p.

2.2.2 Output Resistance

The output resistance is defined as

$$r_d = - \left. \frac{dV_{sd}}{dI_d} \right|_{V_{sg} = \text{constant}} \tag{2-46}$$

Following a process similar to that outlined for the transconductance, the output resistance can also be written in terms of I_s, W_{oo} and a function of s and p.

$$r_d = \left(\frac{W_{oo}}{I_s}\right) \left\{ \frac{2p(1-p) + \xi (l_1/L) \cosh [\pi L_2/2a] -2p (1-p)}{1 - p} \right\} \tag{2-47}$$

$$= \left(\frac{W_{oo}}{I_s}\right) f_r (s,p)$$

where

$$f_r(s,p) = \left\{\frac{[2p(1-p) + \xi(L_1/L)] \cosh [\pi L_2/2a] - 2p(1-p)}{1 - p}\right\} \tag{2-48}$$

2.2.3 Gate-Source Capacitance

The gate-source capacitance is defined as the rate of change of the free charge on the gate electrode with respect to the gate bias voltage when the drain potential is held fixed.

$$C_{sg} = \left.\frac{dQ_g}{dV_{sg}}\right|_{V_{sd} = \text{constant}} \tag{2-49}$$

The gate charge can be obtained by a simple application of Gauss' Law as

$$Q_g = \int \vec{D} \cdot d\vec{s} = \varepsilon_r \varepsilon_o \int \vec{E} \cdot d\vec{s} \tag{2-50}$$

In equation (2-50) the differential surface element of the gate is

$$d\vec{s} = \hat{y}\, Z\, dx \tag{2-51}$$

where $\hat{y}$ is a unit vector normal to the gate surface. Also in equation (2-50) the electric field under consideration is

$$\vec{E} = \hat{y}\, E_y \tag{2-52}$$

or the y component of the field. This electric field has two different expressions:

$E_{y1}(x,a)$ in region I and $E_{y2}(x,a)$ in region II.

From equation (2-12) the field in region I can be calculated as

$$E_{y1}(x,a) = \frac{dW(x)}{db(x)} = \frac{2W_{oo}}{a} [1 - b(x)/a] \tag{2-53}$$

In region II there is an additional component due to the Laplacian potential of equation (2-34); consequently

$$E_{y2}(x,a) = \left.\frac{dW(x)}{db(x)}\right|_{x = L_1} + \left.\frac{d\phi(x_1 y)}{d_y}\right|_{y = a} \tag{2-54}$$

$$= \left(\frac{2W_{oo}}{a}\right) p + E_s \sinh \frac{\pi(x - L_1)}{2a}$$

Substitution of equations (2-52) through (2-54) into equation (2-50) yields

$$Q_g = \left(\frac{2W_{oo}\epsilon_r\epsilon_o}{a}\right)\left[\int_o^{L_1} E_{y1}(x,a)dx + \int_{L_1}^{L} E_{y2}(x,a)dx\right] \tag{2-55}$$

$$= \left(\frac{2W_{oo}\epsilon_r\epsilon_o}{a}\right)\left\{\frac{\frac{2}{3}(p^3 - s^3) - \frac{1}{2}(p^4 - s^4)}{(p^2 - s^2) - \frac{2}{3}(p^3 - s^3)} L_1 + p(1 - L_1)\right.$$

$$\left. + \left(\frac{aE_s}{2W_{oo}}\right)\left(\frac{2a}{\pi}\right)\left[\cosh \frac{\pi(L - L_1)}{2a} - 1\right]\right\}$$

$$= 2qN_o aZ \left\{\frac{f_2(s,p)}{f_1(s,p)} L_1 + pL_2 + \left(\frac{\xi a^2}{\pi L}\right)\left[\cosh \frac{\pi(L - L_1)}{2a} - 1\right]\right\}$$

where

$$f_2(s,p) = \frac{2}{3}(p^3 - s^3) - \frac{1}{2}(p^4 - s^4) \tag{2-56}$$

and the gate-source capacitance expression (2-49) can be obtained from (2-55) by performing the following differentiations[3]

$$C_{sg} = \left.\frac{dQ_g}{dV_{sg}}\right|_{V_{sd} = \text{constant}} = \left.\left(\frac{dQ_g}{dp}\right)\left(\frac{dp}{dV_{sg}}\right)\right|_{V_{sd} = \text{constant}} \tag{2-57}$$

$$= \epsilon_r\epsilon_o Z f_c$$

where $f_c = f_{c1} + f_{c2} + 1.56$

$$f_{c1} = \left(\frac{2}{f_1}\right)\left(\frac{L_1}{a}\right)\left\{f_g\left[\frac{2p^2(1 - p^2) + f_2}{1 - p}\right] - s(1 - s)\right\} \tag{2-58}$$

$$f_{c2}(s,p) = 2\left(\frac{L_2}{a}\right)f_g + (1 - 2pf_g)\left[2\left(\frac{L}{a}\right)\frac{p}{\xi \cosh(\pi L_2/2a)} + \tanh\frac{\pi L_2}{2a}\right] \tag{2-59}$$

The first two terms of the capacitance function, f_c, are the contributions due to region I and region II. The numerical term accounts for the fringing capacitance and is taken from the work of Wasserstrom and McKenna[4].

2.2.4 Gate Charging Resistance

At the present, there is no formal analytic expression for R_i in the two section model of the FET. It is simply assumed that the time constant $\tau = R_i C_{sg}$ is proportional to the transit time through the channel. From the experimental data of Brehm and Vendelin[5] this transit time is set to

$$\tau = R_i C_{sg} = 4 \times 10^{-12} \text{ sec} \tag{2-60}$$

From experimental data this product scales with gate length and consequently equation (2-60) can be written as

$$\tau = K\, L\, R_i\, C_{sg} \tag{2-61}$$

where K is a proportionality constant ($K = 0.5/\mu m$) then from equations (2-60) and (2-61)

$$R_i = \frac{4 \times 10^{-12}}{KLC_{sg}} = \frac{8 \times 10^{-12}}{LC_{sg}} \tag{2-62}$$

where L is in μm.

2.2.5 Summary of the Small Signal Analysis of the Intrinsic FET

It is useful to review the results of this section before proceeding with the noise analysis. The model is based on the assumption that the channel under the gate can be divided into two regions. In the first region, the carrier behavior is ohmic. In the second region the carriers move at a saturated drift velocity that does not increase with increased electric field.

A pair of reduced potentials, s and p, are then defined. A second assumption gives a physical significance to these parameters. One assumes that the electric field component along the channel is much smaller than the component perpendicular to the channel. Then one can determine the electric field and potential in terms of the charge distribution in the channel. From the form of the potential, s can be related to the fractional opening of the channel at the source end of the gate and p can be related to the opening at the interface between regions I and II. This assumption sets limits on the applicability of the model. In practice, it is satisfied for gate lengths somewhat larger than the channel depth. Fortunately, such conditions also correspond to most devices of practical interest.

After defining s and p, the bias conditions, V_{sg} and V_{sd}, are expressed in terms of these parameters. The resulting equations must be solved numerically for practical situations which include parasitic source and drain resistances, but they provide a means of obtaining values for s and p. It is then possible to express all of the small signal parameters in terms of s, p and the physical properties of the FET. The following sections will develop the form of the noise figure, again in terms of the reduced potentials s and p.

3. NOISE ANALYSIS FOR THE INTRINSIC FET

Noise in a microwave GaAs FET is produced by sources intrinsic to the device and thermal sources associated with the parasitic resistances. The intrinsic noise arises from two mechanisms: the first mechanism is the thermal or Johnson noise produced in region I; the second mechanism is the diffusion noise in the velocity saturated section (region II).

It is convenient for noise figure calculations to represent the internal noise sources of the intrinsic FET by noise generators suitably connected to the external terminals as shown in Figure 3-1.

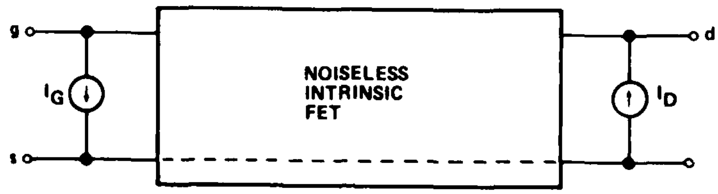


Figure 3-1. The Intrinsic FET with Two Noise Sources
IG Represents the Induced Gate Noise,
ID Represents the Drain Circuit Noise

This representation in terms of external current generators is useful because the output generator can be identified with the short-circuit channel noise generated in the source-drain path, while the input generator can be related to the noise current induced in the gate circuit by the charge fluctuations in the drain current.

3.1 DRAIN CIRCUIT NOISE

The open-circuit drain voltage fluctuation produced by sources in region I is[6]

$$\overline{\left| v_{d1}^2 \right|} = \left(\frac{4kT_0 \Delta f}{2a\sigma \; Z/L_1} \right) \left(\frac{P_0 + P_\delta}{(1-p)^2} \right) \cosh^2 \left(\frac{\pi L_2}{2a} \right) \tag{3-1}$$

where

$$P_0 = (f_1)^{-1} \left[\left(p^2 - s^2\right) - 4/3 \left(p^3 - s^3\right) + 1/2 \left(p^4 - s^4\right) \right] \tag{3-2}$$

and

$$P_\delta = 2\delta\left(f_1^{\ -1}\right)\left(1-p\right)^3\left[(s-p) + \ln\left(\frac{1-s}{1-p}\right)\right] \tag{3-3}$$

The voltage fluctuations are due to Johnson noise generated in region I. Therefore, a kT_0 term occurs in which k is Boltzman's constant and T_0 is the reference temperature (300K) of the channel. Noise is produced over a frequency spectrum and equation (3-1) gives the resulting voltage fluctuations at the drain for a frequency bandwidth Δf. There are two terms in this equation. The first (proportional to P_0) represents the normal Johnson noise contribution as calculated for electrons in region I. The second term (containing P_δ) provides for the fact that the effective noise temperature of the carriers is higher than that of the crystal when an electric field is present to move them through the crystal. This "hot" electron term contains an emperical constant, δ, which relates the effective temperature to the reference temperature, T_0. The value of δ is modified from its published value[7] of 6 to a value of 1.19 to provide for the reduced saturation field of 2.9 kV/cm used here.

The open circuit drain voltage fluctuation produced by sources in region II is[6]

$$\overline{v_{d2}^2} = I_d \frac{64a^2}{\pi^5 V_s^3}\left[\frac{q\ D\Delta f}{(\epsilon_r\epsilon_0)^2 Z^2}\right]\left[\frac{\sin^2 \pi(1-p)/2a}{(1-p)^2}\right]\left[\exp\frac{\pi L_2}{a} - 4\exp\frac{\pi L_2}{2a} + 3 + \frac{\pi L_2}{a}\right] \tag{3-4}$$

This fluctuation in voltage at the drain occurs when dipole layers form in region II of the channel. The layers drift toward the drain with a velocity determined by the diffusion constant, D, of the carriers. When the dipoles form they induce a voltage at the drain and at the region I-region II interface. The voltage appears as a pulse with the pulses described by a frequency spectrum. Equation (3-4) gives the drain voltage fluctuation due to pulses in a frequency bandwidth Δf.

The noise voltage contributions from each region are due to different mechanisms and are uncorrelated. Therefore, their mean squares add. Both contributions are developed across the output resistance, r_d, so the resulting noise fluctuation may be written in terms of a current at the drain, i_d. Specifically:

$$\begin{aligned} i_{d1} &= v_{d1}/r_d \\ i_{d2} &= v_{d2}/r_d \end{aligned} \tag{3-5}$$

$$\overline{i_{d1}^2} + \overline{i_{d2}^2} = \overline{i_d^{\,2}} \tag{3-6}$$

3.2 GATE CIRCUIT NOISE

Noise voltages produced in the channel are coupled capacitively to the gate. These charge fluctuations on the gate in turn modulate the current through the channel and thus appear as noise at the drain. The short-circuit gate current fluctuation produced by sources in region I is given by[6]

$$\overline{\left|i_{g1}^2\right|} = \omega^2\left(\frac{16kT_o\Delta f}{a\sigma/L_1Z}\right)\left(\frac{\epsilon_r\epsilon_oL_1}{\gamma a}\right)^2 (R_o + R_\delta) \tag{3-7}$$

where

$$\gamma = \frac{(1-p)^2\ f_r}{f_1\ \cosh\ (\pi L_2/2a)} \tag{3-8}$$

and

$$R_o = \left(f_1^{-3}\right)\left\{(\kappa')^2(p^2 - s^2) - 4/3\kappa'(\kappa' + \gamma)(p^3 - s^3) + 1/2\left[(\kappa')^2 + 4\kappa'\gamma + \gamma^2\right]\right.$$
$$\left.\cdot\left(p^4 - s^4\right) - 4/5\left(\kappa'\gamma + \gamma^2\right)\left(p^5 - s^5\right) + \gamma^2/3\left(p^6 - s^6\right)\right\} \tag{3-9}$$

$$R_\delta = \delta\ (1-p)^3\ (f_1)^{-3}\left\{-2(\kappa'-\gamma)^2\left[p-s + \ln\left(\frac{1-p}{1-s}\right)\right] + (2\kappa'\gamma - \gamma^2)(p^2-s^2) - 2/3\ \gamma^2\ (p^3-s^3)\right\} \tag{3-10}$$

$$\kappa = (f_1)^{-1}\left[-1/3\ (p^3-s^3) + 1/6\ (p^4-s^4) + (s^2-2/3\ s^3)\ (p-s)\right] + \gamma p \tag{3-11}$$

$$\kappa' = \kappa + (L_2/L_1)\ (1 - p) \tag{3-12}$$

Notice that this noise term is similar to the region I channel contribution (3-1). The observation is not surprising because both contributions are due to the same Johnson noise generated in region I. Because the boundary of region I is not a short circuit, but the conditions of region II, γ is included to represent the modified boundary condition. If region II were not present, ($L_2 = 0$) the hyperbolic cosine term in (3-8) would be one and $\gamma = 1$. That is, one would have the short-circuit condition again.

The short-circuit gate current fluctuations produced by sources in region II are given by[6]

$$\overline{\left|i_{g2}^2\right|} = \omega^2 I_d\left(\frac{64a^3qD\Delta f}{\pi^5V_s^5}\right)\left[\frac{L_1\kappa'(\gamma = 0)}{\epsilon_r\epsilon_oaZ(1 - p)^2r_d}\right]^2\sin^2[\pi(1 - p)/2]$$
$$\cdot\left(\exp\ \pi L_2/a - 4\ \exp\ \pi L_2/2a + 3 + \pi L_2/a\right) \tag{3-13}$$

This contribution is quite similar to the drain circuit noise (3-4) which is also produced by the formation of dipole layers in region II.

3.3 THE CORRELATION COEFFICIENT

The Johnson noise produced in region I and the noise due to dipole layer generation in region II are independent of each other. However, the noise contributions from gate and drain for a given region are correlated. There is full correlation between i_{g2} and i_{d2} with a capacitive 90 degree phase shift between the currents. Thus,

$$\overline{i_{g2} * i_{d2}} = j\left(\left[\left|\overline{i_{g2}^2}\right|\right] \cdot \left[\left|\overline{i_{d2}^2}\right|\right]\right)^{1/2} \tag{3-14}$$

The correlation between i_{g1} and i_{d1} is not complete and the combined noise current is given by[8]

$$\overline{i_{g1} * i_{d1}} = j\left[\frac{S_o + S_\delta}{(R_o + R_\delta)^{1/2}(P_o + P_\delta)^{1/2}}\right]\left(\left[\left|\overline{i_{g1}^2}\right|\right] \cdot \left[\left|\overline{i_{d1}^2}\right|\right]\right)^{1/2} \tag{3-15}$$

where

$$\begin{aligned} S_o = (f_1)^{-2}\Big\{&\kappa \cdot \left[(p^2 - s^2) - 4/3\,(p^3 - s^2) + 1/2\,(p^4 - s^4)\right] \\ &+ \gamma\left[-\,2/3\,(p^3 - s^3) + (p^4 - s^4) - 2/5\,(p^5 - s^5)\right]\Big\} \end{aligned} \tag{3-16}$$

$$S_\delta = 2\delta(f_1)^{-2}(1 - p)^3\left\{(\kappa' - \gamma)\left[s - p + \ln\left(\frac{1 - s}{1 - p}\right)\right] + 1/2\,\gamma(p^2 - s^2)\right\} \tag{3-17}$$

The overall correlation coefficient is defined by the expression

$$\begin{aligned} jC &= \overline{i_g^* i_d}\Big/\left(\left|\overline{i_g^2}\right|\left|\overline{i_d^2}\right|\right)^{1/2} \\ &= \left[\frac{S_o + S_\delta}{\left(R_o + R_\delta\right)^{1/2}\left(P_o + P_\delta\right)^{1/2}}\right] \cdot \left(\frac{\overline{i_{g1}^2}}{\overline{i_g^2}}\right)^{1/2}\left(\frac{\overline{i_{d1}^2}}{\overline{i_d^2}}\right)^{1/2} + \left(\frac{\overline{i_{g2}^2}}{\overline{i_g^2}}\right)^{1/2}\left(\frac{\overline{i_{d2}^2}}{\overline{i_d^2}}\right)^{1/2} \end{aligned} \tag{3-18}$$

Substitution of equations (3-1) through (3-7), and equation (3-13) in equation (3-18) yields

$$C = \frac{S_o + S_\delta}{(R_o + R_\delta)^{1/2}\,(P_o + P_\delta)^{1/2}}\sqrt{\frac{P_1 R_1}{PR}} + \sqrt{\frac{P_2 R_2}{PR}} \tag{3-19}$$

where

$$P_1 = \frac{(1 - p)}{f_1 f_g \gamma^2}(P_o + P_\delta) \tag{3-20}$$

$$P_2 = \frac{1 - p}{\xi f_r^2 f_g}\left(\frac{L}{a}\right) f_3 \tag{3-21}$$

$$P = P_1 + P_2 \tag{3-22}$$

$$R_1 = 4\left(\frac{L}{a}\right)^2 \left(\frac{f_1}{1 - p}\right)^3 \left(\frac{1}{\xi\gamma}\right)^2 \left(\frac{f_g}{f_c^2}\right)(R_o + R_\delta) \tag{3-23}$$

$$R_2 = 4\left(\frac{L}{a}\right)^3 \left[\frac{1}{\xi(1 - p)}\right]^3 \left(\frac{f_1^2 f_g}{f_r^2 f_c^2}\right) [\kappa'(\gamma = o)]^2 f_3 \tag{3-24}$$

$$R = R_1 + R_2 \tag{3-25}$$

$$f_3 = \frac{16}{\pi^3}\left(\frac{D}{D_o}\right)\left[\frac{\sin(\pi/2)(1 - p)}{(\pi/2)(1 - p)}\right]^2 \left(\exp\frac{\pi L_2}{a} - 4 \exp\frac{\pi L_2}{2a} + \frac{\pi L_2}{a}\right) \tag{3-26}$$

The final form of the correlated noise, given by (3-19), reflects the partial correlation between region I contributions (the first term) and the total correlation between region II contributions (the second term). The noise figure developed in the following sections will be expressed in terms of the quantities R, P and C listed here.

4. NOISE FIGURE ANALYSIS FOR THE FET

4.1 INTRODUCTION

The noise figure analysis to follow will be based on the equivalent circuit for the FET shown in Figure 2-3. The assumed configuration will be common source, with the gate considered as the input port and the drain considered as the output port. This configuration was chosen because it represents the typical front-end stage of a microwave receiver. Due to the amplification mechanism of the FET; the greater contribution to the overall noise figure of the device is provided by those elements connected to the input port; while the contribution to the noise by the elements connected to the output port is small; under this line of reasoning the noise contribution of the drain resistance and, the drain-gate capacitance C_{dg}, the source drain capacitance C_{sd}, and the parasitic resistance R_d (see Figure 2-3) can be neglected without incurring significant error and greatly simplifying the equivalent circuit to be used in the noise analysis (see Figure 4-1).

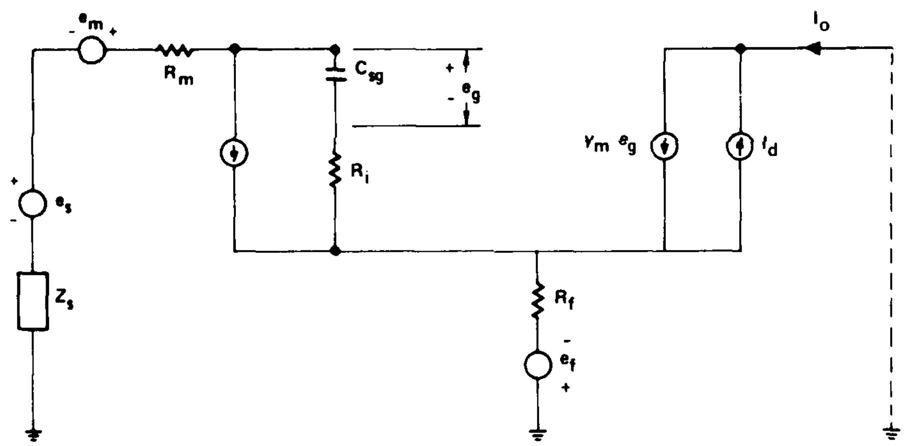


Figure 4-1. Simplified Equivalent Circuit Model

4.2 NOISE FIGURE DERIVATION

The intrinsic FET shown in the simplified schematic of Figure 4-1 can be represented by two short-circuit Y parameters.

$$Y_{11} = \frac{j\omega C_{sg}}{1 + j\omega C_{sg} R_i} \tag{4-1}$$

$$Y_{21} = \frac{g_m}{1 + j\omega C_{sg} R_i} \tag{4-2}$$

Also, the noise Figure F for this simplified circuit can be expressed as

$$F = 1 + \frac{\overline{|i_g + i_s + i_{go} + i_{do}|^2}}{\overline{|i_z|^2}} \tag{4-3}$$

where i_g, i_s, i_{go}, i_{do}, and i_z are the noise components in the short-circuited drain-source path produced by the noise generators e_{gn}, e_{sn}, i_g, i_d, and e_{zn}, respectively. The noise generators representing the extrinsic thermal sources R_g, R_s, and the real part of Z_s are given by their mean square values as

$$\overline{|e_{gn}^2|} = 4kT_o R_g \Delta f \tag{4.4}$$

$$\overline{|e_{sn}^2|} = 4kT_o R_s \Delta f \qquad (T_o = 300^oK) \tag{4.5}$$

$$\overline{|e_{zn}^2|} = 4kT_o (\mathrm{Re} Z_s) \Delta f \tag{4.6}$$

where "Re" denotes "real part of"

Analyzing the circuit of Figure 4-1, equation (4.3) can alternatively be expressed as

$$F = 1 + \frac{1}{\mathrm{Re} Z_s} \left\{ R_g + R_s + |R_g + R_s + Z_s|^2 \frac{\overline{|i_g^2|}}{4kT_o\Delta f} \right.$$

$$+ \left| \frac{1 + Y_{11} (R_g + R_s + Z_s)}{Y_{21}} \right|^2 \frac{\overline{|i_d^2|}}{4kT_o\Delta f} \tag{4.7}$$

$$\left. - 2\mathrm{Re} \left[(R_g + R_s + Z_s) \left(\frac{1 + Y_{11} (R_g + R_s + Z_s)}{Y_{21}} \right)^* \frac{\overline{i_g^* i_d}}{4kT_o\Delta f} \right] \right\}$$

The terms of equation (4-7) that contain the intrinsic noise current sources i_g and i_d can be written alternatively as

$$\left|\frac{\overline{i_g^{\,2}}}{4kT_o\Delta f}\right| = \frac{\omega^2 C_{sg}^{\,2}}{g_m} R \tag{4-8}$$

$$\left|\frac{\overline{i_d^{\,2}}}{4kT_o\Delta f}\right| = g_m P \tag{4-9}$$

$$\frac{\overline{i_g{}^* i_d}}{4kT_o\Delta f} = \frac{jC\left(\left|\overline{i_g^{\,2}}\right|\left|\overline{i_d^{\,2}}\right|\right)^{1/2}}{4kT_o\Delta f} = jC\,\omega C_{sg}\,(RP)^{1/2} \tag{4-10}$$

where R_1, P, and C are defined by equations (3-25), (3-22) and 3-19), respectively.

4.3 MINIMUM NOISE FIGURE

From equation (4-7) and using equations (4-8), (4-9), and (4-10) the minimum noise figure can be evaluated by setting the partial derivative of the noise figure with respect to the source impedance Z_s equal to 0. This yields

$$Z_s\,opt = R_s opt + j\,X_s\,opt \tag{4-11}$$

where

$$R_s opt = \left\{\left(R_g + R_s + Re\left[\frac{1 - C\,(R/P)^{1/2}}{Y_{11}\,[1 - C(R/P)^{1/2}]^2 - (1 - C^2)\,R/P}\right]\right)^2 + \left[\frac{g_m\left(R_g + R_s\right) + K_r\left(1 + \omega^2 C_{sg}^{\,2} R_i^{\,2}\right)}{\omega^2 C_{sg}^{\,2}\,K_g}\right]^2\right\}^{1/2} \tag{4-12}$$

$$X_s opt = -Im\left[\frac{1 - C(R/P)^{1/2}}{Y_{11}\,[1 - C(R/P)^{1/2}]^2 - (1 - C^2)R/P}\right] \tag{4-13}$$

where

$$K_r = \frac{R(1 - C^2)}{[1 - C\,(R/P)^{1/2}]^2 + (1 - C^2)\,R/P} \tag{4-14}$$

and "Im" denotes "imaginary part of." Also

$$K_g = P\left\{[1 - C(R/P)^{1/2}]^2 + (1 - C^2)\ R/P\right\} \qquad (4\text{-}15)$$

With this optimum source impedance given by equation (4-11) the minimum noise figure can be found by substitution of equation (4-11) into equation (4-7). Also since the noise figure is a frequency dependent function, equation (4-7) can be expanded as a power series in ω; this yields

$$F_{min} = 1 + 2\left(\frac{f}{f_T}\right)\left\{PR\ (1 - C^2) + g_m \left(\frac{T}{T_o}\right)(R_g + R_s)\left|P(1 - C(R/P)^{1/2})^2 + R(1 - C^2)\right|\right\}^{1/2}$$

$$+ 2\left(\frac{f}{f_T}\right)^2\left\{g_m\left(\frac{T}{T_o}\right)(R_g + R_s)\ P\left|(1 - C(R/P)^{1/2})^2 + ((1 - C^2)\ R/P)\right| \qquad (4\text{-}16)$$

$$+ g_m\ R_i P\ \left[1 - C(R/P)^{1/2}\right]\right\}$$

where the term $\omega C_{sg}/g_m$ in the expansion has been expressed as f/f_T ($f_T = g_m/2\pi C_{sg}$). f_T is the gain-bandwidth product of the FET or the frequency at which the current gain of the device drops to unity.

4.4 TEMPERATURE EFFECTS ON NOISE FIGURE

From Equation (4-16) the straight-forward dependence of noise figure on the device temperature can be observed in the terms that contain the ratio T/T_o. There is, however, a very strong dependence of gain on the ratio T/T_o given by the expression

$$g_m = \frac{f_g(s,p)}{W_{oo}}\ (2aZE_s)\ (\mu_o N_o)\left(\frac{T}{T_o}\right)^{1.5} \qquad (4\text{-}17)$$

From equations (4-16) and (4-17), it can clearly be observed that the dependence of noise figure on temperature can best be evaluated by a numerical process. After describing the contributions of the ancillary regions to FET noise figure, the results of the numeral analysis will be presented.

5. FET WITH VARIABLE DOPING PROFILE

5.1 SMALL SIGNAL PARAMETERS

Consider the FET as shown in Figure 2-5 with a doping concentration N(y) which is a function of the depth below the gate. It is convenient for the analysis to follow, to change the coordinate system in Figure 2-5 such that $y = 0$ at the upper left-hand corner of the region under the gate and consider only the upper half of the device. By Poisson's equation

$$\frac{dE_y}{dy} = \frac{q}{\varepsilon_r \varepsilon_o} N(y) \tag{5-1}$$

and

$$E_y(y) = \frac{q}{\varepsilon_r \varepsilon_o} \left[\overline{N(y)} + C_1\right] \tag{5-2}$$

where the notation $\overline{N(y)}$ represents

$$\int_0^y N(y)\, dy$$

Similarly, (5-3)

$$\overline{\overline{N(y)}} = \int_0^y \overline{N(y)}\, dy$$

At the depletion depth $y = y_d$, it is required that $E_y = 0$; thus from equation (5-2)

$$E_y(y_d) = \frac{q\left[\overline{N(y_d)}\right]}{\varepsilon_r \varepsilon_o} + C_1 = 0 \tag{5-4}$$

and

$$E_y(y) = \frac{q}{\varepsilon_r \varepsilon_o} \left[\overline{N(y)} - \overline{N(y_d)}\right] \tag{5-5}$$

The potential across the depletion layer can be obtained by direct integration of equation (5-5). Thus,

$$W(y) = \int \bar{E}_y \cdot d\bar{y} = \int E_y dy = \frac{q}{\varepsilon_r \varepsilon_o} \left[\overline{\overline{N}(y)} - y\, \overline{N(y_d)} + C_2\right] \qquad (5\text{-}6)$$

since $W(y) = 0$ at $z = 0$ the constant C_2 in equation (5-6) can be evaluated as $C_2 = -\overline{\overline{N(0)}}$

and

$$W(y) = \frac{q}{\varepsilon_r \varepsilon_o} \left[\overline{\overline{N(y)}} - y\, \overline{N(y_d)} - \overline{\overline{N(0)}}\right] \qquad (5\text{-}7)$$

Equation (5-7) is analogous to equation (2-12) of the constant doping profile case. It is convenient for the following analysis to introduce the dimensionless variable $\omega = y/a$ † where ω runs from 0 to 1 across the epilayer; using this dimensionless variable equation (5-7) can be rewritten as

$$W(\omega) = \frac{qa^2}{\varepsilon_r \varepsilon_o} \left[\overline{\overline{N(\omega)}} - \omega\, \overline{N(\omega_d)}\right] \qquad (5\text{-}8)$$

where the term $\overline{\overline{N(0)}} = 0$ has been dropped.

In equation (5-8)

$$\overline{N(\omega)} = \int_0^{\omega} N(\omega) d\omega \text{ and } \overline{\overline{N(\omega)}} = \int_0^{\omega} \overline{N(\omega)} d\omega$$

The potential across the depletion region is $W(\omega_d)$ where

$$W(\omega_d) = \frac{qa^2}{\varepsilon_r \varepsilon_o} \left[\overline{\overline{N(\omega_d)}} - \omega_d\, \overline{N(\omega_d)}\right] \qquad (5\text{-}9)$$

By considering the integral

$$\int_0^{\omega_d} \omega\, N(\omega) d\omega$$

† ω when used as normalized channel depth is not to be confused with angular frequency.

and integrating by parts; it can be shown that:

$$\int_0^{\omega_d} \omega\ N(\omega)\ d\omega = \omega_d\ \overline{N(\omega_d)} - \int_0^{\omega_d} N(\omega)\ d\omega \tag{5-10}$$

thus equation (5-9) can be alternately written as

$$W(\omega_d) = \frac{-qa^2}{\varepsilon_r\varepsilon_o} \int_0^{\omega_d} \omega\ N(\omega)\ d\omega \tag{5-11}$$

Using equation (5-11), the potential required to deplete the entire epilayer of carriers is

$$W_{oo} = \frac{qa^2}{\varepsilon_r\varepsilon_o}\left[\overline{N(1)} - \overline{\overline{N(1)}}\right] = \frac{qa^2}{\varepsilon_r\varepsilon_o}\int_0^{1} \omega\ N(\omega)\ d\omega \tag{5-12}$$

The potential expressed by equation (5-12) is analogous to W_{oo} of equation (2-6) for the constant doping profile case.

To calculate the total drain current flowing in the channel, one can follow a procedure very similar to that of Section 2.2, equations (2-16) through (2-20), and by Ohm's law at a distance x from the source

$$I_d = q\mu_o Z\left[\int_{y_d}^{a} N(y_d)\ dy\right] E_x(x) \tag{5-13}$$

Using the dimensionless variable ω, equation (5-13) can also be written as

$$\begin{aligned} I_d &= q\mu_o ZaE_x(x) \int_{\omega_d}^{1} N(\omega)\ d\omega \\ &= q\mu_o ZaE_x(x)\ \left[\overline{N(1)} - \overline{N(\omega_d)}\right] \end{aligned} \tag{5-14}$$

To evaluate $E_x(x)$ one can start from equation (2-2) properly modified for the variable profile case, thus:

$$E_x(x) = -\frac{dV(x)}{dx} \tag{5-15}$$

$$E_x(x) = -\frac{d}{dx}\left[V_{sg} + \phi - W(\omega_d)\right]$$

$$E_x(x) = \frac{d\omega_d}{dx} \cdot \frac{dW(\omega_d)}{d\omega_d}$$

and from equation (5-11)

$$\frac{dW(\omega_d)}{d\omega_d} = \frac{qa^2}{\varepsilon_r\varepsilon_o}\,\omega_d\, N(\omega_d) \tag{5-16}$$

Using equations (5-15) and (5-16), equation (5-14) becomes:

$$I_d = \frac{\mu_o Z q^2 a^3}{\varepsilon_r\varepsilon_o}\left[\overline{N(1)} - \overline{N(\omega d)}\right]\omega_d\, N(\omega_d)\,\frac{d\omega_d}{dx} \tag{5-17}$$

Integration of equation (5-17) over the length of region I i.e., from $x = 0$ to $x = L_1$ yields (dropping subscripts)

$$I_d = \frac{\mu_o Z q^2 a^3}{\varepsilon_r\varepsilon_o L_1}\, f_1(s,p) \tag{5-18}$$

where

$$f_1(s,p) = \overline{N(1)}\int_s^p \omega N(\omega)d\omega - \int_s^p \omega N(\omega)\,\overline{N(\omega)}\,d\omega \tag{5-19}$$

In equation (5-19) the quantities s and p represent the values of $\omega = y/a$ at $x = 0$ and $x = L_1$, respectively. Also the function $f_1(s,p)$ described by equation (5-19) is analogous to the one described by equation (2-20) in the constant doping profile case.

From the general equations (2-3) and (2-4) it can be concluded that the potential drop from $x = 0$ to $x = L_1$ (across region I) is

$$V(L_1) - V(0) = W_p - W_S \tag{5-20}$$

Also since at $x = L_1$ the carriers reach their saturation velocity and $E_x(x) = E_s$, then the expression for the drain current in region II is

$$I_d = q\mu_o Z a E_s\left[\overline{N(1)} - \overline{N(p)}\right] \tag{5-21}$$

Thus equations (2-3), (2-4), (5-18), (5-19), (5-20), and (5-21) establish relations between the quantities s, p, L_1 and I_d to the potentials V_{sg}, $V(L_1)$ and the corresponding doping density integrals.

In region II the potential function $\phi(x,y)$ is assumed to be determined by the charges in the depleted region and free charges on the drain electrode, consequently,

$$\phi(x,y) = \phi_1(x,y) + \phi_2(x,y) \tag{5-22}$$

where $\phi_1(x,y)$ is the potential due to the depletion charges and $\phi_2(x,y)$ is the potential due to free charges on the drain. To solve for $\phi_2(x,y)$ the process to follow is that of Section 2.2, equations (2-31) and (2-32); this yields the result.

$$\phi_2(x,y) = \frac{2a}{\pi} E_s \sin\left(\frac{\pi y}{2a}\right)\sinh\left[\frac{\pi(x - L_1)}{2a}\right] \tag{5-23}$$

From equation (5-7) the potential $\phi_1(x,y)$ is obtained as

$$\phi_1(x,y) = \frac{q}{\varepsilon_r\varepsilon_o}\left[\overline{\overline{N(y)}} - y\, \overline{N(pa)}\right] \tag{5-24}$$

However, this potential given by equation (5-24) gives no E_x contribution in region II, gives zero electric field at the channel and zero potential at $y = 0$; consequently, the potential due to $\phi_1(x,y) + \phi_2(x,y)$ measured along the channel from $x = L_1$ to $x = L_2$ is due entirely to ϕ_2. Adding the potential drop from $x = 0$ to $x = L$ one can obtain from equations (5-20) and (5-23) the source to drain voltage given by

$$V_{sd} = W(p) - W(s) + \frac{2a}{\pi} E_s \sinh\left[\frac{\pi(L - L_1)}{2a}\right] \tag{5-25}$$

Equation (5-25) with equations (5-18) and (5-20) enables one to solve for the current-voltage relationship of the FET. From equations (5-18) and (5-21) I_d can be eliminated; this yields

$$L_1 = \frac{qa^2}{\varepsilon_r\varepsilon_o E_s}\left[\frac{f_1(s,p)}{\overline{N(1)} - \overline{N(p)}}\right] \tag{5-26}$$

Equation (5-26) is analogous to equation (2-25) for the constant profile case but $f_1(s,p)$ is given in this case by equation (5-19).

Just as in the constant doping profile case, equations (5-25) and (5-26) form a pair must be solved simultaneously in order to determine p, s, then L_1 and I_d.

5.1.1 Transconductance

Following the same procedure as the one outlined in Section 2.2.1 and from equations (2-38), (5-11), (5-20), (5-21), (5-25), and (5-26), the expression for the

transconductance for the variable doping profile case can be shown to be

$$g_m = \frac{\varepsilon_r \varepsilon_o \mu_o Z\ E_s}{a} f_g(s,p) \tag{5-27}$$

where

$$f_g(s,p) = \frac{[\overline{N(1)} - \overline{N(s)}] \cosh (\pi L_2/2a) - [\overline{N(1)} - \overline{N(p)}]}{\left\{p[\overline{N(1)} - \overline{N(p)}] + \varepsilon_r \varepsilon_o E_s L_1/qa^2\right\} \cosh (\pi L_2/2a) - p[\overline{N(1)} - \overline{N(p)}]} \tag{5-28}$$

This expression given by equation (5-28) reduces to that of equation (2-45) when $N(\omega) = N_o$ = constant.

5.1.2 Output Resistance

Following the same procedure as the one outlined in Section 2.2.2 and using equations (2-46), (5-25), and (5-26) the expression for the output resistance can be obtained as

$$r_d = \frac{a}{\varepsilon_r \varepsilon_o \mu_o Z\ E_s} f_r(s,p) \tag{5-29}$$

where

$$f_r(s,p) = \frac{[\cosh (\pi L_2/2a) - 1] \left\{p[(\overline{N(1)} - \overline{N(p)}]\right\} + (\varepsilon_r \varepsilon_o E_s L_1/qa^2) \cosh (\pi L_2/2a)}{\overline{N(1)} - \overline{N(p)}} \tag{5-30}$$

5.1.3 Gate Source Capacitance

From Section 2.2.3 and using equations (2-49), (5-23) through (5-26) the gate-source capacitance can be expressed as

$$C_{sg} = C_1 + C_2 + 1.56\ \varepsilon_r \varepsilon_o Z \tag{5-31}$$

where C_1 and C_2 are the capacitance contributions due to regions I and II, respectively. The numerical term accounts for the fringing capacitance as in the constant profile case. The capacitance contribution due to region I is given by

$$C_1 = \frac{qaZ}{E_s} \left\{ f_g(s,p) \left[p\overline{N(p)} + \frac{f_2(s,p)}{[\overline{N(1)} - \overline{N(p)}]^2} \right] - \left[\frac{\overline{N(1)} - \overline{N(S)}}{\overline{N(1)} - \overline{N(p)}} \right] \overline{N(s)} \right\} \tag{5-32}$$

where

$$f_2(s,p) = \overline{N(1)} \int_s^p \omega_d N(\omega_d)\ \overline{N(\omega_d)}\ d\omega_d - \int_s^p \omega_d N(\omega_d)\ [\overline{N(\omega_d)}]^2\ d\omega_d \tag{5-33}$$

and the capacitance contribution due to region II is

$$C_2 = \frac{\varepsilon_r \varepsilon_o Z\ L_2}{a} f_g(s,p) + \left[\frac{qaZ\overline{N(p)} + \varepsilon_r \varepsilon_o Z\ E_s \sinh(\pi L_2/2a)}{E_s \cosh(\pi L_2/2a)}\right] \cdot \left[1 - f_g(s,p)\right] \tag{5-34}$$

5.1.4 <u>Gate Charging Resistance</u>

On the basis of the assumption of Section 2.2.4 that the time constant $\tau = R_i\ C_{sg}$ is proportional to the transit time through the channel one can write

$$\tau = \int_o^{L_1} \frac{dx}{\mu_o E_x(x)} + \int_{L_1}^{L} \frac{dx}{v_s} \tag{5-35}$$

The first integral on the right-hand side of equation (5-35) can be evaluated using equations (5-14) and (5-17) thus:

$$\frac{1}{\mu_o} \int_o^{L_1} \frac{dx}{E_x(x)} = \frac{q^3 \mu_o Z^2 a^4}{\varepsilon_r \varepsilon_o I_d^2} \int_o^{L_1} [\overline{N(1)} - \overline{N(\omega_d)}]\ \omega_d N(\omega_d)\ d\omega_d \tag{5-36}$$

The second integral on the right-hand side of equation (5-35) is simply L_2/v_s, consequently, from equations (5-35) and (5-36)

$$R_i = \frac{1}{C_{sg}} \left[\frac{q^3 \mu_o Z^2 a^4}{\varepsilon_r \varepsilon_o I_d^2} \int_o^{L_1} [\overline{N(1)} - \overline{N(\omega_d)}]\ \omega_d N(\omega_d)\ d\omega_d + \frac{L_2}{\mu_o E_s}\right] \tag{5-37}$$

5.2 NOISE ANALYSIS FOR THE INTRINSIC FET WITH VARIABLE DOPING PROFILE

5.2.1 Drain Circuit Noise

The open-circuit voltage fluctuation produced by sources in region I for the variable doping profile case is

$$\left|\overline{v_{d1}^{2}}\right| = \frac{4kT\,\Delta f}{I_d}\left(\frac{P_o + P_\delta}{\left[\overline{N(1)} - \overline{N(p)}\right]^2}\right)\cosh^2\left(\frac{\pi L_2}{2a}\right) \tag{5-38}$$

where

$$P_o = \int_s^p \left[\overline{N(1)} - \overline{N(\omega)}\right]^2 \omega\, N(\omega)\, d\omega \tag{5-39}$$

and

$$P_\delta = \delta\left[\overline{N(1)} - \overline{N(p)}\right]^3 \int_s^p \frac{\omega\, N(\omega)\, d\omega}{\left[\overline{N(1)} - \overline{N(\omega)}\right]} \tag{5-40}$$

whereas the open circuit drain voltage fluctuation produced by sources in region II is given by the same expression as for the constant doping profile case or equation (3-4), equations (5-38) through (5-40) are analogous to equations (3-1) through (3-3), respectively. As in the constant doping profile case, the noise voltage contributions of the two regions are uncorrelated and their mean squares added.

5.2.2 Gate Circuit Noise

The short-circuit gate current fluctuation produced by sources in region I for the variable doping profile is

$$\left|\overline{i_{g1}^{2}}\right| = \omega^2\left(\frac{qaZL_1}{r_d I_d}\right)^2\left(\frac{qa^2}{\epsilon_r\epsilon_o I_d}\right)\frac{\cosh^2(\pi L_2/2a)}{\left[\overline{N(1)} - \overline{N(p)}\right]^2}(R_o + R_\delta) \tag{5-41}$$

where

$$\gamma = 1 + \left(\frac{qa^2}{\epsilon_r\epsilon_o}\right)\frac{p\left[\overline{N(1)} - \overline{N(p)}\right]}{E_s L_1}\left[1 - \frac{1}{\cosh(\,L_2/2a)}\right] \tag{5-42}$$

and

$$R_o = \int_s^p \left[-\kappa' + \gamma \overline{N(\omega_d)}\right]^2 \left[\overline{N(1)} - \overline{N(\omega_d)}\right]^2 \omega_d N(\omega_d) d\omega_d \tag{5-43}$$

$$R_\delta = \delta \left[\overline{N(1)} - \overline{N(p)}\right]^3 \int_s^p \frac{\left[-\kappa' + \gamma \overline{N(\omega_d)}\right]^2}{\left[\overline{N(1)} - \overline{N(\omega_d)}\right]} \omega_d N(\omega_d) d\omega_d \tag{5-44}$$

$$\kappa' = \frac{\mu_o q^2 a^3 Z}{\varepsilon_r \varepsilon_o I_d L_1} \int_s^p f_1 (\omega_d, s) N(\omega_d) d\omega_d + \int_o^p \gamma N(\omega_d) d\omega_d + \frac{L_2}{L_1} \left[\overline{N(1)} - \overline{N(p)}\right] \tag{5-45}$$

Equations (5-41) through (5-45) are analogous to equations (3-7) through (3-10) and equation (3-12) respectively for the constant doping profile case.

The short circuit gate current fluctuation produced by sources in region II is given by the same expression as for the constant doping profile case or equation (3-13).

5.2.3 Correlation Coefficient

Following the same argument given in Section 3.3, the correlation coefficient C is given by equation (3-19) in which the expressions for P_o, P_δ, R_o, R_δ are given by equations (5-39), (5-40), (5-43) and (5-44), respectively. For S_o and S_δ the expressions are

$$S_o = -\int_s^p \left[-\kappa' + \gamma \overline{N(\omega_d)}\right] \left[\overline{N(1)} - \overline{N(\omega_d)}\right]^2 \omega_d N(\omega_d) d\omega_d \tag{5-46}$$

$$S_\delta = -\delta \left[\overline{N(1)} - \overline{N(p)}\right]^3 \int_s^p \left[\frac{-\kappa' + \gamma \overline{N(\omega_d)}}{\overline{N(1)} - \overline{N(\omega_d)}}\right] \omega_d N(\omega_d) d\omega_d \tag{5-47}$$

and for P_1, P_2, P , R_1, R_2 and R the expressions are

$$P_1 = \left(\frac{qa^2}{\varepsilon_r \varepsilon_o r_d^2 g_m I_d}\right) \frac{\cosh^2 (\pi L_2/2a)}{\left[\overline{N(1)} - \overline{N(p)}\right]^2} (P_o + P_\delta) \tag{5-48}$$

$$P_2 = \left(\frac{a I_d}{4\ g_m r_d^{\ 2}\ \mu_o^{\ 2}\ E_s^{\ 3}\ \varepsilon_r^{\ 2}\ \varepsilon_o^{\ 2}\ Z^2} \right) f_3 \tag{5-49}$$

$$P = P_1 + P_2 \tag{5-50}$$

$$R_1 = \left(\frac{q^3 a^4 Z^2 L_1^{\ 2} g_m}{r_d^{\ 2}\ \varepsilon_r \varepsilon_o I_d^{\ 3}\ C^2_{\ sg}} \right) \frac{\cosh^2\ (\pi L_2/2a)}{[\overline{N(1)} - \overline{N(p)}]^2} (R_o + R_\delta) \tag{5-51}$$

$$R_2 = \left(\frac{q^2 a^3 L_1^{\ 2} g_m}{4 r_d^{\ 2}\ \varepsilon_r^{\ 2}\ \varepsilon_o^{\ 2}\ I_d\ C^2_{\ sg}\ \mu_o^{\ 2}\ E_s^{\ 3}} \right) (\kappa')^2\ f_3 \tag{5-52}$$

$$R = R_1 + R_2 \tag{5-53}$$

The function f_3 of equations (5-49) and (5-52) is the same as for the constant doping profile case and is given by equation (3-26).

5.3 NOISE FIGURE ANALYSIS FOR THE INTRINSIC FET

The process to follow in order to obtain the noise figure for the FET with variable doping profile is the same as the one outlined in Section 4.2; this leads to identical expressions as those given in that section; consequently, they will not be rewritten here. It must be understood, however, that the expressions for P_1, P_2, P, R_1 and R_2 are given by equations (5-48) through (5-52), respectively. The same line of argument is followed for the minimum noise figure derivation of Section 4.3 and the temperature effects on noise figure expression of Section 4.4.

6. ANCILLARY REGIONS

For the purpose of developing analytical expressions for the parasitic resistance R_g, R_s, and R_d it is convenient to set up a coordinate system and establish dimensions (see Figure 2-4) as shown in Figure 6-1.

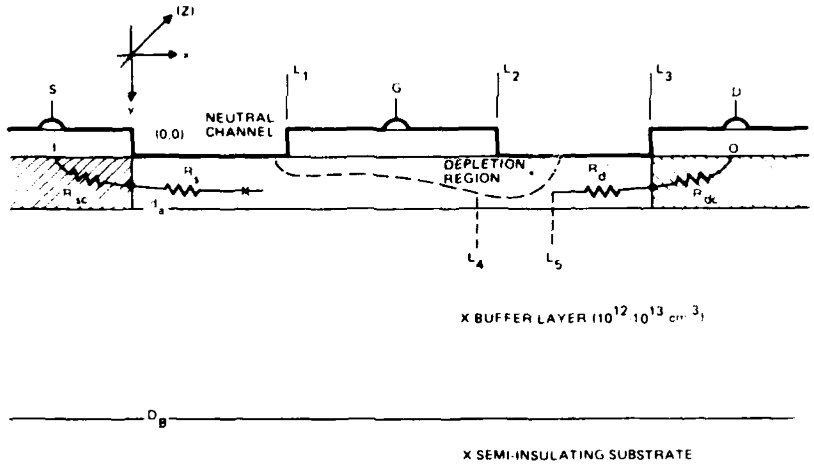


Figure 6-1. FET Cross-section

6.1 PARASITIC SOURCE RESISTANCE

The parasitic source series resistance consists of a metal sheet resistance term similar to the gate series resistance, but also includes contact resistance from metal to GaAs (R_{sc}) and channel resistance between the gate and source contact metallizations (R_s'). If ρ_{sch} is the sheet resistance of the channel, R_s' (Figure 6-1) may be estimated as

$$R_s' = \frac{\rho_{sch} L_1}{Z} \tag{6-1}$$

The contact resistance may be described as a distributed resistor network as indicated in Figure 6-2. The equations which describe this system are

$$I(x) = \int_0^x V(x)\, G\, dx \; ; \text{ or, } \frac{\partial I}{\partial x} = V(x)\, G \tag{6-2}$$

$$V(x) = V(0) + \int_0^x I(x)\, R\, dx \; ; \text{ or, } \frac{\partial V}{\partial x} = I(x)\, R \qquad (6\text{-}3)$$

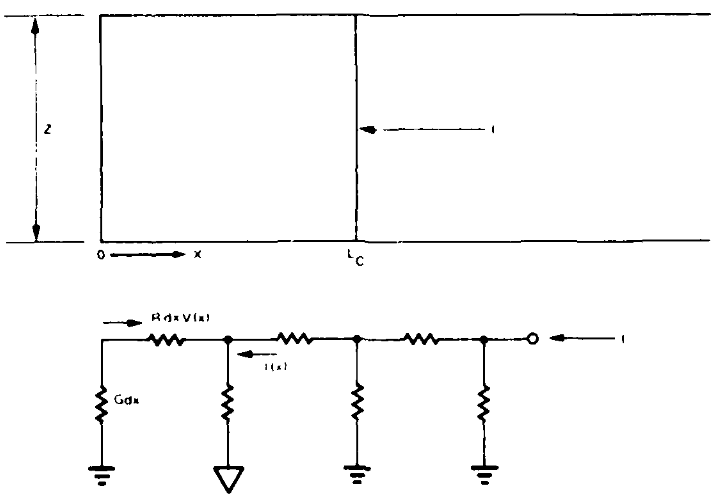


Figure 6-2. Contact Resistance and Equivalent Circuit

These can be combined to a single equation

$$\frac{\partial^2 I}{\partial x^2} = RG\, I(x) \qquad (6\text{-}4)$$

G is determined by the specific contact resistance, ρ_c, which is typically 10^{-4} Ω - cm^2

$$G = \frac{Z}{\rho_c}$$

R is determined by the sheet resistance of the GaAs under the contact metal. For an active implant of $10^{14}/cm^2$, this sheet should be $\rho_{sco} \approx 15\ \Omega/\square$

$$R = \frac{\rho_{sco}}{Z}$$

thus

$$\gamma^2 = RG = \left(\frac{\rho_{sco}}{\rho_c}\right) \approx 1.5 \times 10^5$$

solutions to 6.3 have the form

$$I = Ae^{\gamma x} + Be^{-\gamma x} \qquad (6\text{-}5)$$

The boundary conditions are that

$$I = 0 \text{ @ } x = 0$$

$$I = I_c \text{ @ } x = L_c$$

thus

$$I = I_c \left(e^{\gamma x} - e^{-\gamma x}\right) \Big/ \left(e^{\gamma L_c} - e^{-\gamma L_c}\right) \qquad (6\text{-}6)$$

$$V(x) = \frac{1}{G}\frac{\partial I}{\partial x}$$

or

$$V(x) = \frac{I_c \gamma}{G}\left[\frac{(e^{\gamma x} + e^{-\gamma x})}{\left(e^{\gamma L_c} - e^{-\gamma L_c}\right)}\right] \qquad (6\text{-}7)$$

Contact resistance is $V(L_c)/I(L_c)$, so

$$R_{sc} = \frac{(\gamma/G)\left(e^{\gamma L_c} + e^{-\gamma L_c}\right)}{\left(e^{\gamma L_c} - e^{-\gamma L_c}\right)}$$

but

$$\gamma = \sqrt{RG}$$

so

$$R_{sc} = \frac{(\rho_{sco}\ \rho_c)^{1/2}}{Z}\left(\frac{1 + e^{-2\gamma L_c}}{1 - e^{-2\gamma L_c}}\right) \tag{6-8}$$

Clearly, the most effective way to minimize R_{sc} is to minimize both ρ_{sco} and ρ_c and make $2\gamma L_c >> 1$. For the values quoted, $2\gamma L_c \approx 1$ at $L_c = 13\ \mu m$, indicating that contact resistance cannot be improved by making contacts longer than about 40 μm. Total resistance R_s is therefore

$$R_s = \frac{(\rho_{sco}\ \rho_c)^{1/2}}{Z}\frac{\left(1 + e^{-2\ \frac{(\rho_{sco})^{1/2}}{(\rho_c)^{1/2}}\ L_c}\right)}{\left(1 - e^{-2\ \frac{(\rho_{sco})^{1/2}}{(\rho_c)^{1/2}}\ L_c}\right)} + \frac{\rho_{sch}\ L_1}{Z} + \frac{\rho_{shs}\ L_c}{2Z} \tag{6-9}$$

here

ρ_{sco} = sheet resistance of GaAs under contact metal

ρ_c = specific contact resistivity – metal to GaAs

ρ_{sch} = sheet resistance of channel between contact and gate

L_c = contact length

L_1 = space contact to gate

ρ_{shs} = sheet resistance of source contact metal

Z = device width

6.2 PARASITIC DRAIN RESISTANCE

The parasitic drain resistance R_d is calculated the same way as R_s, with L_1 replaced by $L_3 - L_2$ and L_c replaced by the drain contact length. In fact, most device designs have symmetrical source and drain geometries, leading to $R_d = R_s$.

6.3 PARASITIC GATE RESISTANCE

The parasitic gate series resistance R_g is due to the series resistance of the gate metallization; for the single lump equivalent circuit it is the resistance from the gate terminal to the center of the device

$$R_g \approx \frac{\rho_{shg} Z}{2\ L_g} \tag{6-10}$$

where ρ_{shg} is the sheet resistance of the gate metallization, Z is the gate width, and L_g is the gate length ($L_g = L_2 - L_1$ in Figure 6-1). R_g can be minimized by keeping ρ_{shg} low (thick aluminum) or by keeping the effective Z small by paralleling several devices with small gate widths rather than using a single device with large gate width.

6.4 SOURCE-DRAIN AND GATE-DRAIN CAPACITANCES

The expression for inter-electrode capacitances between parallel strips immersed in an infinite dielectric medium was developed by Smythe[9]; modifying his expression to account for the air dielectric above the electrodes the expression for both capacitances C_{dg} and C_{sd} becomes

$$C_{dg}, C_{sd} = (\epsilon_r + 1)\, \epsilon_o Z \frac{K\left[(1-k^2)^{1/2}\right]}{K(k)} \tag{6-11}$$

where K(k) is the complete elliptical integral of the first kind given by[10]

$$K(k) = \int_0^{\pi/2} (1 - k \sin^2 \theta)^{-1/2} \, d\theta \tag{6-12}$$

the argument k of equations (6-11) and (6-12) is given by

$$k_{dg} = \left[\frac{L_3 - L_2}{(L_3 - L_2) + (L_2 - L_1)}\right]^{1/2}$$

$$k_{sd} = \left[\frac{(2L_s + L_3)L_3}{(L_s + L_3)^2}\right]^{1/2}$$

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APPENDIX B
FET MODELING CODE LISTING

The following is a complete listing of the FET modeling code. The major program is written in FORTRAN. The program is followed by a listing, which begins on page B-70, of the subprogram used to investigate the effects of a nonuniform vertical doping profile. The subprogram is written in BASIC.

```
*MAIN
      PROGRAM MAIN(INPUT, OUTPUT, TAPE3, TAPE4=INPUT,TAPE5=OUTPUT,
     1              TAPE6,TAPE7)
C
C     THIS PROGRAM IS BASED UPON A MODEL FOR FET SIGNAL AND NOISE
C PROPERTIES AS DEVELOPED BY PUCEL, HAUS, AND STATZ.
C
      COMMON/CONSTS/ECHARG,AMLO,ESAT,DIELC,BOLTZK,DIFCON,PI
      COMMON/SYTRAP/GL,Z,A,DOPEC,T,VGG,VDD,RPF,RPDR,RPM,ATITLE(7),PHI,F,
     1        IPROFIL,DOPIN(101),DOP(101),DOPB(101),DOP2B(101)
      COMMON/CALC/P,S,GO,AISAT,AID,WCO,SATDEX,ARGU
      COMMON/PARPUT/EMIN,GM,CSG,CGD,CSD,RPI,GL1,GL2,RD,RSOPT,XSOPT
      COMMON/TOPLT/FX(50),FY(50,10),FG(50),NPT,NLN
      COMMON/ANCPAR/ESG,SL,DOPES,DOPESG,RSCS,RSHS,RSHG,SGD,DL,
     1              DOPED,DOPEGD,RSCD,RSHD,IREG,ISYM
C
      REWIND 3
      REWIND 6
      DISPLAY*                FET ANALYSIS*
90    DISPLAY*ENTER THE NUMBER OF THE OPTION DESIRED.  IF UNFAMILIAR *
      DISPLAY*WITH THIS PROGRAM, ENTER 1 FOR FURTHER INFORMATION.*
      ACCEPT IOP
      IF (IOP.NE.1) GO TO 15
10    DISPLAY*     THIS PROGRAM CONTAINS SEVERAL OPTIONS.  THE *
      DISPLAY*OPTION NUMBERS ARE LISTED BELOW.*
      DISPLAY* *
      DISPLAY*1-      DISPLAYS THE OPTION LIST.*
      DISPLAY* *
      DISPLAY*2-      COMPUTES THE NOISE FIGURE AND TRANSCONDUCTANCE*
      DISPLAY*        FOR A GIVEN SET OF INPUT PARAMETERS.  ALSO*
      DISPLAY*        PROVIDES EXTENSIVE LISTING OF OTHER COMPUTED*
      DISPLAY*        VALUES.  PROVIDES OPTION TO USE VALUES TO*
      DISPLAY*        CREATE A FILE FOR RUNNING WITH COMPACT.  THE*
      DISPLAY*        COMPACT RUN WILL PROVIDE S PARAMETERS FOR*
      DISPLAY*        THE GIVEN FET.*
      DISPLAY* *
      DISPLAY*3-      COMMPUTES THE NOISE FIGURE AND TRANSCONDUCTANCE*
      DISPLAY*        AS A FUNCTION OF ONE OF THE INPUT PARAMETERS.*
      DISPLAY* *
      DISPLAY*4-      THIS OPTION ALLOWS ONE TO QUICKLY ENTER ALL*
      DISPLAY*        INITIAL DATA.  IT ASSUMES THAT THE USER IS*
      DISPLAY*        FAMILIAR WITH THE PROGRAM.*
```

```
      DISPLAY* *
      DISPLAY*5-     COMPUTES PARASITIC RESISTANCE IN THE*
      DISPLAY*       ANCILLARY REGIONS AND THE INTERELECTRODE*
      DISPLAY*       CAPACITANCE.  THIS OPTION IS ALSO AVAILABLE*
      DISPLAY*       IN CONJUNCTION WITH NOISE CALCULATION*
      DISPLAY*       OPTIONS.*
      DISPLAY*  *
      DISPLAY*6-     COMPUTES THE DC CHARACTERISTICS, DRAIN VOLTAGE*
      DISPLAY*       VERSUS CURRENT.  THE RESULTS ARE COMPUTED AS A*
      DISPLAY*       FUNCTION OF A THIRD VARIABLE AND OUTPUT AS*
      DISPLAY*       TABLES OR PLOTS.*
      DISPLAY*  *
      DISPLAY*7-     COMPUTES NOISE FIGURE AND TRANSCONDUCTANCE AS*
      DISPLAY*       A FUNCTION OF ONE OF THE INPUT PARAMETERS AS*
      DISPLAY*       DOES OPTION 3.  HOWEVER, THE DOPING CONCENTRA-*
      DISPLAY*       TION IS OPTIMIZED TO PRODUCE THE MINIMUM NOISE*
      DISPLAY*       FIGURE IN EACH CASE.*
      DISPLAY*  *
      DISPLAY*ENTER THE DESIRED OPTION*
      ACCEPT IOP
C
C                          CONSTANTS
C  PERMITTIVITY OF FREE SPACE, ELECTRONIC CHARGE, SATURATED
C  ELECTRIC FIELD, DIELECTRIC CONSTANT
15    EPSO = 8.854E-14
      ECHARG = -1.602E-19
      ESAT = 2900
      DIELC = 12.5*EPSO
      BOLTZK = 1.3806E-23
      DIFCON = 35.
      PI = 3.14159
16    GO TO (10,20,30,40,50,60,70) IOP
20    CALL OPTION1 (IOP)
      GO TO 85
30    CALL OPTION2 (IOP)
      GO TO 85
40    CALL PARTRTN (IOP)
      GO TO 85
50    CALL ANCIL (IOP)
      GO TO 85
60    CALL IVCHAR (IOP)
      GO TO 85
```

```
70    CALL OPTION2(IOP)
65    IF (IOP.EQ.0) GO TO 99
      GO TO [illegible]
99    STOP
      END
```

```
*OP 1
      SUBROUTINE OPTION1 (IOP)
C
C  THIS SUBROUTINE OUTPUTS DETAILED LISTING FOR ONE SET OF INPUT
C  PARAMETERS
C
      COMMON/CONSTS/ECHARG,AMUO,ESAT,DIELC,BOLTZK,DIFCON,PI
      COMMON/EXTPAR/GL,Z,A,DOPEC,T,VGC,VDD,RFF,RPDR,RPM,ATITLE(7),PHI,F,
     1         IPROFIL,DOPIN(101),DOP(101),DOPB(101),DOP2B(101)
      COMMON/CALC/F,S,CO,AISAT,AID,WCL,SATDEX,APGU
      COMMON/PAROUT/FMIN,GM,CSG,CGD,CSD,RPI,GL1,GL2,RD,RSOPT,XSOPT
      COMMON/ANCPAR/SSG,SL,DOPES,DOPESG,RSCS,RSHS,RSHG,SGD,DL,
     1                DOPED,DOPEGD,RSCD,RSHD,IREG,ISYM
C
      DISPLAY*ENTER A DESCRIPTIVE HEADING FOR THIS RUN.*
      READ(4,210) ATITLE
210   FORMAT (7A10)
      IF (IOP.GT.0) CALL VALUES(IOP)
      IF (IOP.LT.0) IOP = -1*IOP
216   IWOO = 0
      IF (VDD.GT.-90.) GO TO 218
      IWOO = 1
      VDD = (-1.)*WOO
218   DISPLAY*CALCULATE PARASITICS? (0=NO 1=TRW 2=FUKUI)*
      ACCEPT IPARAS
      IF (IPARAS.EQ.1) CALL ANCIL(IOP)
      IF (IPARAS.EQ.2) CALL ANCIL2(IOP)
      IF (IPARAS.EQ.1) GO TO 220
C
C  IF ANCIL IS NOT CALLED...CGD AND CSD CALCULATED.  STOGRAT IS THE
C  RATIO OF SOURCE CONTACT LENGTH TO GATE LENGTH.  INTERELECTRODE
C  DISTANCES EQUAL GATE LENGTH.
C
      STOGRAT = 2.
      CGD = 13.5/12.5*DIELC*Z
      AMOD3 = SQRT((9.+6.*STOGRAT)/(3.+STOGRAT)**2)
      AMOD4 = SQRT(1.-AMOD3*AMOD3)
      CSD = CGD*ELLIP(AMOD4)/ELLIP(AMOD3)
220   CALL VALUES2(IOP)
      CALL PCALC(IERR)
      IF (IERR.NE.99) GO TO 230
      CALL NEWVAL
```

```
      GO TO 220
230   ISMOKE = 0
      IF (IDPS.NE.-1) CALL CRUNCH(IDARK )
      IF (IDP2.EQ.-1) CALL CRUNCH(I * * )
      IF (ISHOWE.EQ.E2) GO TO 254
C
C  BEGIN DETAILED OUTPUT
C
      GMO = GM*1.E3
      GMTERMO = GMO/(1.+GM*RPF)
      GANBWO = GM/2./PI/CSG/1.E9
      WRITE(5,234) FMIN,GMO,GMTERMO,GANBWO
      WRITE(7,234) FMIN,GMO,GMTERMO,GANBWO
234   FORMAT(1H ,10X,*NOISE FIGURE =*,F6.4,* DB*,/,7X,*TRANSCONDUCT*,
     1        *ANCE =*,F6.2,*   MMHO*,/,12X,*TERMINAL GM =*,F6.2,
     2        *   MMHO*,/,6X,*CUT-OFF FREQUENCY =*,F6.2,*   GHZ*,/)
      IF (IERR.EQ.-1) WRITE (5,235)
      IF (IERR.EQ.-1) WRITE (7,235)
235   FORMAT(2H *,*   ELECTRON VELOCITY SATURATED OVER ENTIRE GATE*,
     1        * REGION.  THE*,/,1H ,*    ACCURACY OF THESE PREDICTIONS*,
     2        * IS UNVERIFIED.*)
      WRITE (5,236)
      WRITE (7,236)
236   FORMAT(1H ,*CAPACITANCE (PF)*,20X,*RESISTANCE (OHM)*,/,22X,
     1        *INTRINSIC*)
      CSGD = CSG*1.E12
      CGDD = CGD*1.E12
      WRITE(5,238) CSGD,RPI,CGDD,RD
      WRITE(7,238) CSGD,RPI,CGDD,RD
238   FORMAT(1H ,*CSG =*,F6.4,25X,*RI (GATE CHARGE) =*,F8.2,/,* CGD =*
     1        ,F6.4,30X,*RD (OUTPUT) =*,F8.2,/,22X,*PARASITIC*)
      CSDD = CSD*1.E12
      WRITE(5,240) CSDD,RPM,RPF,RPDR
      WRITE(7,240) CSDD,RPM,RPF,RPDR
240   FORMAT(1H ,*CSD =*,F6.4,26X,*RM (GATE METAL) =*,F8.2,/,42X,
     1        *RF (SOURCE) =*,F8.2,/,42X,*RDR (DRAIN) =*,F8.2)
      WRITE(5,242)
      WRITE(7,242)
242   FORMAT(1H ,/,5X,*REGION I*,20X,*REGION II*)
      GL1D =GL1*1.E4
      GL2D = GL2*1.E4
      GL1PT = GL1*100./GL
```

```
      GL2PT = GL2*100./GL
      WRITE(5,244) GL1D,GL2D,GL1PT,GL2PT,S,P
      WRITE(7,244) GL1D,GL2D,GL1PT,GL2PT,S,P
244   FORMAT(1H ,* L1 =*,F6.3,* MICRONS*,22X,*L2 =*,F6.3,* MICRONS*,
     1        /,5X,*=*,F6.2,* S*,30X,*=*,F6.2,* S*,/,*   S =*,
     2        F9.7,27X,*P =*,F9.7)
      AIDD = AID*1.E3
      AISATD = AISAT*1.E3
      WRITE(5,246) AIDD,AISATD
      WRITE(7,246) AIDD,AISATD
246   FORMAT(1H ,/,16X,*ADDITIONAL PARAMETERS*,/,*  ID =*,F7.2,
     1        * MA*,25X,*IS =*,F7.2,* MA*)
      GOD = GO*1.E3
      WRITE(5,248) VDD,PHI,GOD,SATDEX
      WRITE(7,248) VDD,PHI,GOD,SATDEX
248   FORMAT(1H ,*VDD =*,F7.3,* V*,25X,*PHI =*,F7.3,* V*,/,
     1        *  GO =*,F7.3,* MMHO*,19X,*SATDEX =*,F7.3)
      ESATD = ESAT*1.E-3
      DIELCD = DIELC*1.E12
      VS = AMUO*ESAT
      WRITE(5,250) ESATD,AMUO,VS,DIFCON,DIELCD
      WRITE(7,250) ESATD,AMUO,VS,DIFCON,DIELCD
250   FORMAT(1H ,* ES =*,F7.3,* KV/CM*,21X,*MUO =*,F7.1,* CM2/V/SEC*,
     1        /,*  VS =*,E9.2,* CM/SEC*,15X,*DIFCON =*,F7.1,* CM2/SEC*,/,
     2        38X,*DIELC =*,F7.3,* PF/CM*,/,1H )
      GAIN = -99.
      CALL SPAR(IDD,GAIN)
      DISPLAY*  *
      DISPLAY*  *
      DISPLAY*CREATE FILE FOR COMPACT? (1=YES)*
      ACCEPT ISPAR
      IF (ISPAR.EQ.1) CALL COMPREP(IDD)
254   DISPLAY*NEXT, MAKE A REVISED RUN (-1), CHANGE OPTION (0) OR*
      DISPLAY*CONCLUDE SESSION (1)?*
      ACCEPT IWANT
      IF (IWANT) 260,270,280
260   VDDOLD = VDD
      CALL NEWVAL
264   CALL CHECK (IDD)
      IF (VDD.NE.VDDOLD) IWDD = 0
      IF (IWDD.EQ.1) VDD = (-1.)*WDD
      IF (VDD.GT.-90.) GO TO 266
```

```
      VDD = (-1.)*WOO
      INCC = 1
266   DISPLAY*NEW DESCRIPTIVE HEADING?*
      READ (4,200) ATITLE
      GO TO 219
270   RETURN
280   IOP = 0
      RETURN
      END
```

```
*OP 2
      SUBROUTINE OPTION2 (IOP)
C
C  THIS SUBROUTINE CALCULATES NOISE WHILE VARYING ONE INPUT PARAMETER
C
      COMMON/CONSTS/ECHARG,AMUO,VSAT,DIELC,BOLTZK,DIFCON,PI
      COMMON/EXTPAR/GL,Z,A,DOPEC,T,VGG,VDD,RPF,RPDR,RPM,ATITLE(7),PHI,F,
     1       IPROFIL,DOPIN(101),DOP(101),DOPR(101),DOP2B(101)
      COMMON/CALC/P,S,CS,AISAT,AIO,WOO,SATD,X,APGU
      COMMON/PAROUT/FMIN,GM,CSG,CGD,CSD,RPI,GL1,GL2,RD,RSOPT,XSOPT
      COMMON/TOPLT/FX(50),FY(50,10),FG(50),NPT,NLN
      COMMON/ANCPAR/SSG,SL,DOPES,DOPESG,RSCS,RSHS,RSHG,SGD,DL,
     1             DOPED,DOPLGD,RSCD,RSHD,IPEG,ISYM
C
      DISPLAY*ENTER A DESCRIPTIVE HEADING FOR THIS RUN.*
      READ(4,310) ATITLE
310   FORMAT (7A10)
      DISPLAY*CALCULATE S-PARAMETERS TOO (1=YES)?*
      ACCEPT ISPAR
      IF (IOP.GT.0) CALL VALUES(IOP)
      IF (IOP.LT.0) IOP = -1*IOP
      IWOO = 0
      IF (VDD.GT.-90.) GO TO 311
      IWOO = 1
      VDD = (-1.)*WOO
C
311   DISPLAY*CALCULATE PARASITICS?(0=NO  1=TRW  2=FUKUI)*
      ACCEPT IPARAS
      IF (IPARAS.EQ.1) CALL ANCIL(IOP)
      IF (IPARAS.EQ.2) CALL ANCIL2(IOP)
312   DISPLAY*NUMBER OF PARAMETER TO BE VARIED?  (0=LIST)*
      ACCEPT IWANT
      IF (IWANT.NE.0) GO TO 316
      DISPLAY*GATE LENGTH            1*
      DISPLAY*GATE WIDTH             2*
      DISPLAY*CHANNEL DEPTH          3*
      DISPLAY*DOPING DENSITY         4*
      DISPLAY*DEVICE TEMP            5*
      DISPLAY*GATE BIAS              6*
      DISPLAY*DRAIN BIAS             7*
      DISPLAY*RSG                    8*
      DISPLAY*RGD                    9*
```

```
      DISPLAY*SIGNAL FREQ              10*
      DISPLAY*BUILT-IN POTENTIAL       11*
      DISPLAY*GATE RESISTANCE          13*
      DISPLAY*DIFFUSION CONSTANT       15*
      DISPLAY*TURN ON OR OFF THE OPTION TO SET VGG AUTOMATICALLY*
      DISPLAY*TO A FRACTION OF PINCH-OFF                         16*
315   DISPLAY*ENTER THE NUMBER OF THE PARAMETER YOU WANT TO VARY.*
      ACCEPT IWANT
316   IF (IWANT.NE.16) GO TO 318
C
C  SET OPTION TO ADJUST VGG TO A FRACTION OF PINCH-OFF
C
      DISPLAY*THE GATE VOLTAGE CAN BE SET TO A FRACTION OF PINCH-OFF*
      DISPLAY*(1=OPTION ON  0=OPTION OFF)*
      ACCEPT IBIAS
      IF (IBIAS.EQ.0) GO TO 312
      DISPLAY*WILL SET VGG = X(WOO-PHI).  ENTER X*
      ACCEPT FBIAS
      GO TO 312
C
318   IREVIZ = 99
      IF (IPARAS.EQ.1) CALL ANCIL(IREVIZ)
      IF (IPARAS.EQ.2) CALL ANCIL2(IREVIZ)
320   IF (IOP.EQ.7.AND.IWANT.EQ.4) GO TO 400
      DISPLAY*INITIAL AND FINAL VALUES AND INTERVAL SIZE FOR*
      DISPLAY*VARIED PARAMETER2*
      ACCEPT VAR1,VAR2,VINT
      IF (VAR1.GT.VAR2.AND.VINT.GT.0) VINT = -1.*VINT
      CALL VALUES2(IOP)
      GO TO (451,452,453,454,455,456,457,458,459,460,461,462,463,
     1       464,465) IWANT
325   N = INT((VAR2-VAR1)/VINT)+1
      NPT = N
      IUSEC2 = 0
      IPC2 = 0
C
C  LOOP THROUGH CALCULATIONS FOR EACH VALUE OF PARAMETER
C
      DO 350 I=1,N
      VAR = VAR1+(I-1.)*VINT
      FX(I) = VAR
      GO TO (371,372,373,374,375,376,377,378,379,380,381,382,383,
```

```
     1         384,385) THANT
330   IF (IPTAP.EQ.1) VGS = FRIAS*(450.-RH-I)
      IF (ITP.EQ.7) GO TO 404
      IERR = 0
      CALL PCALC (IERR)
      IF (IERR.EQ.-1) THSLO2 = 1
      IF (IERR.EQ.99) GO TO 350
      ISMOKE = 0
      IF (IERR.NE.-1) CALL CRUNCH(ISMOKE)
      IF (IERR.EQ.-1) CALL CRUNCH2(ISMOKE)
      AISATP = AISAT*1.E3
      AIDD = AID*1.E3
      GMD = GM*1.E3
      GMTHRAT = GMD/(1.+GM*RS)
      IF (ISMOKE.EQ.99) GO TO 334
      GAMPAC = GM/2./PI/CGG/1.E9
C
C  GAIN CALCULATED IS MAX AVAILABLE POWER GAIN FOR THE PROPERLY
C  MATCHED DEVICE (MATCHED FOR OPTIMUM NOISE FIGURE).  THEREFORE
C  IT IS THE ASSOCIATED GAIN IF THE DEVICE IS STABLE.  OTHERWISE
C  IT IS THE MAXIMUM STABLE GAIN.
C
      IF (IPARAP.EQ.1) GO TO 332
C
C  IF ANCIL IS NOT CALLED...CGD AND CSD CALCULATED.  STOGRAT IS THE
C  RATIO OF SOURCE CONTACT LENGTH TO GATE LENGTH.  INTERELECTRODE
C  DISTANCE IS EQUAL GATE LENGTH.
C
      STLGRAT = 20.
      CGD = 13.5/12.5*DIELC*Z
      AMOD3 = SQRT((9.+6.*STOGRAT)/(3.+STOGRAT)**2)
      AMOD4 = SQRT(1.-AMOD3*AMOD3)
      CSD = CGD*ELLIP(AMOD4)/ELLIP(AMOD3)
C
C  TO SET CSD AND CGD TO ARBITRARY VALUES SET ICAP TO 1
C
      ICAP = 0
      IF (ICAP.NE.1) GO TO 332
      CSDF = CSD*1.E12
      CGDF = CGD*1.E12
      WRITE(5,331) CSDD,CGDD
      WRITE(7,331) CSDD,CGDD
```

```
331    FORMAT(1H ,*CSD =*,F7.4,* AND CGD =*,F7.4,*  ENTER NEW VALUES*)
       ACCEPT CSDP,CGDP
       CSD = CSDP*1.E-12
       CGD = CGDP*1.E-12
332    CALL SPAR(IOP,GAIN)
       FG(I) = GAIN
334    FY(I,1) = FMIN
       IF (IWANT.NE.4) GO TO 336
       VAR = VAR*1.E-17
336    IF (IERR.EQ.-1) GO TO 338
C
C  NORMAL OUTPUT
C
       WRITE (5,340) VAR,AIDE,GMT,RMD,CMC,FMIN,GANBWD,WOD,GAIN
       WRITE (7,340) VAR,AIDE,GMT,RMD,GMC,FMIN,GANBWD,WOD,GAIN
       GO TO 344
C
C  NORMAL OUTPUT WITH * TO DENOTE CRUNCH2 USED
C
338    WRITE (5,342) VAR,AIDE,GMT,RMD,GMC,FMIN,GANBWD,WOD,GAIN
       WRITE (7,342) VAR,AIDE,GMT,RMD,GMC,FMIN,GANBWD,WOD,GAIN
340    FORMAT (1H ,F11.2,F9.1,F8.2,*/*,F5.2,F11.4,F9.2,F10.2,F7.2)
342    FORMAT(1H ,1H*,F10.2,F9.1,F8.2,*/*,F5.2,F11.4,F9.2,F10.2,F7.2)
344    IF (ISPAR.NE.1) GO TO 350
       GFLAG = -99.
       CALL SPAR(IOP,GFLAG)
350    CONTINUE
       IF (ILSSC2.EQ.0) GO TO 354
       WRITE(5,352)
       WRITE(7,352)
352    FORMAT(1H ,/,2H *,*  ELECTRON DRIFT VELOCITY SATURATED FOR *,
     1        *ENTIRE GATE REGION.  TH*,/,1H ,*    ACCURACY OF THESE*,
     2        * PREDICTIONS IS UNVERIFIED.*)
354    DISPLAY*  *
       DISPLAY*  *
       DISPLAY*DO YOU WANT A NOISE FIGURE PLOT?(1=YES)*
       ACCEPT IPLOT
       IF (IPLOT.NE.1) GO TO 358
       NLN = 1
       CALL FETPLOT (IOP,IWANT,ATITL )
358    WRITE(5,360)
360    FORMAT (//,*NEXT, MAKE A REVISED RUN (-1), CHANGE OPTION (0)*,
```

```
1         /,*OR CONCLUDE SESSION (1)2*)
      ACCEPT IWANT
      IF (IWANT) 362,366,368
362   DISPLAY*FIRST RESET ANY VALUES.*
      VDDOLD = VDD
      CALL NEWVAL
      CALL CHECK(IOP)
      IF (VDD.NE.VDDOLD) IWDD = 1
      IF (IWDD.EQ.1) VDD = (-1.)*WDD
      IF (VDD.GT.-99.) GO TO 364
      IWDC = 1
      VDD = (-1.)*WDD
364   DISPLAY*ENTER ANOTHER DESCRIPTIVE TITLE*
      READ (4,330) ATITLE
      GO TO 315
366   RETURN
368   ICP = 0
      RETURN
C
C  REVISE VALUE OF PARAMETER AND CALL CHECK
C
371   GL = VAR*1.E-4
      GO TO 390
372   Z = VAR*1.E-4
      GO TO 390
373   A = VAR*1.E-4
      GO TO 390
374   DCREC = VAR
      GO TO 390
375   T = VAR
      GO TO 390
376   VGG =VAR
      GO TO 330
377   VDD = VAR
      GO TO 330
378   RFF = VAR
      GO TO 330
379   RFUP = VAR
      GO TO 330
380   F = VAR*1.E0
      GO TO 330
381   PHI = VAR
```

```
      GO TO 394
382   DISPLAY*PROGRAM ERROR*
      RETURN
383   REM = VAR
      GO TO 330
384   DISPLAY*YOU CAN NOT REACH THIS PART OF THE PROGRAM+*
      RETURN
385   DIFCON = VAR
      GO TO 330
389   IR_VIZ = 20
      IF (IPARAS.EQ.1) CALL ANCIL(IOP)
      IF (IPARAS.EQ.2) CALL ANCIL2(IOP)
390   IFLAG = -1
      CALL CHECK (IFLAG)
      IF (IWOO.EQ.1) VOO = (-1.)*WOO
391   IF (IFLAG.NE.-2) GO TO 330
      WRITE (5,392) VAR
392   FORMAT (E15.2,10X,*WOO > PHI*)
      GO TO 350
394   IPHI = INT(PHI*1000.)
      CALL CHECK (IPHI)
      GO TO 391
C
C   THIS SECTION CONTROLS THIS SUBROUTINE WHEN OP 7 IS CHOSEN.
400   DISPLAY*OPTION 7 AUTOMATICALLY VARIES THE DOPING CONCEN-*
      DISPLAY*TRATION TO OBTAIN THE MINIMUM NOISE FIGURE.  YOU*
      DISPLAY*MUST CHOOSE A DIFERENT PARAMETER TO VARY.*
      GO TO 312
C
C   THE NOISE FIGURE IS OPTIMIZED BY VARYING DOPEC.  THE ROUTINE
C   OPERATES ON THE ASSUMPTION THAT THE OPTIMUM IS NEAR
C   10**17 ATOMS/CC.  IN ADDITION, IT MUST BE POSSIBLE TO
C   COMPUTE THE NOISE FIGURE AT THIS INITIAL CONCENTRATION.
404   DOPEC = 1.E17
      IF (IPARAS.EQ.1) IOP = 17
      CALL NOISE(IOP,IUSEC2)
      IF (FMIN.GT.0.) GO TO 408
      FY(I,1) = 0.
      WRITE(5,406) VAR
406   FORMAT(E11.2,4X,*NOISE FIGURE CANNOT BE CALCULATED.*)
      IOP = 7
      FY(I,1) = 0.
```

```
      GO TO 350
406   FAT17 = FMIN
      FSAVE = FMIN
      DOPEC = 0.E16
      ST = 1.E16
410   CALL NOISE(IOP,TUSEC2)
      IF (FMIN.GT.FSAVE) GO TO 422
      IF (FMIN.EQ.0.) GO TO 418
414   FSAVE = FMIN
      DOPEC = DOPEC-ST
      GO TO 410
418   FSAVE = 1000.
      DOPEC = DOPEC+2.*ST
      ST = ST/10.
      GO TO 410
422   IF (FSAVE.NE.FAT17) GO TO 430
      DOPEC = 1.E17
      CALL NOISE(IOP,TUSEC2)
      IF (FMIN.GT.FAT17) GO TO 426
      ST = -1.E16
      GO TO 414
426   ST = 1.E15
      FAT17 = -99.
      GO TO 414
430   IF (ST.EQ.1.E16) GO TO 418
      DOPEC = DOPEC+ST
      FMIN = FSAVE
      FY(I,1) = FMIN
      AISATD = AISAT*1.E3
      AIDD = AID*1.E3
      GMD = GM*1.E3
      GMTERMD = GMD/(1.+GM*RPF)
      GAMPWT = GM/2./PI/CSG/1.E9
      IF (IFARAS.EQ.1) GO TO 432
      STOGRAT = 20.
      CGD = 13.5/12.5*DIELC*Z
      AMOD3 = SQRT((2.+6.*STOGRAT)/(3.+STOGRAT)**2)
      AMOD4 = SQRT(1.-AMOD3*AMOD3)
      CSD = CGD*ELLIP(AMOD4)/ELLIP(AMOD3)
432   CALL SPAR(IOP,GAIN)
      FG(I) = GAIN
      IF (IUSEC2.EQ.1) GO TO 438
```

```
C
C   NORMAL OUTPUT
C
      WRITE (5,340) VAR,AIDO,GMTERMO,GMO,FMIN,GANBWO,WOO,GAIN
      WRITE (7,340) VAR,AIDO,GMTERMO,GMO,FMIN,GANBWO,WOO,GAIN
      GO TO 444
438   WRITE(5,342) VAR,AIDO,GMTERMO,GMO,FMIN,GANBWO,WOO,GAIN
      WRITE(7,342) VAR,AIDO,GMTERMO,GMO,FMIN,GANBWO,WOO,GAIN
      IPC2 = IUSEC2
444   WRITE(5,446) DOPEC
      WRITE(7,446) DOPEC
446   FORMAT(1H ,48X,*AT*,E10.2,* ATOMS/CC*)
      IF (ISPAR.NE.1) GO TO 450
      GAIN = -99.
      CALL SPAR(IOP,GAIN)
450   IOP = 7
      IUSEC2 = IPC2
      GO TO 350
C
C   END OF NOISE OPTIMIZATION ROUTINE.
C
451   WRITE (5,471)
      WRITE (7,471)
471   FORMAT(1H ,*    GATE LENGTH*,3X,*ID*,6X,*GMT/GM*,
     1          9X,*N.F.*,7X,*FT*,7X,*WOO    GAIN*,/)
      GO TO 325
452   WRITE (5,472)
      WRITE (7,472)
472   FORMAT(1H ,*     GATE WIDTH*,3X,*ID*,6X,*GMT/GM*,
     1          9X,*N.F.*,7X,*FT*,7X,*WOO    GAIN*,/)
      GO TO 325
453   WRITE (5,473)
      WRITE (7,473)
473   FORMAT(1H ,*  CHANNEL DEPTH*,3X,*ID*,6X,*GMT/GM*,
     1          9X,*N.F.*,7X,*FT*,7X,*WOO    GAIN*,/)
      GO TO 325
454   WRITE (5,474)
      WRITE (7,474)
474   FORMAT(1H ,*DOPE CON X1E-17 *,3X,*ID*,6X,*GMT/GM*,
     1          9X,*N.F.*,7X,*FT*,7X,*WOO    GAIN*,/)
      GO TO 325
455   WRITE (5,475)
```

```
      WRITE (7,475)
475   FORMAT(1H ,*     TEMPERATURE=*,3X,*ID*,6X,*GMT/GM*,
     1        9X,*N.F.*,7X,*FT*,7X,*WOO    GAIN*,/)
      GO TO 325
456   WRITE (5,476)
      WRITE (7,476)
476   FORMAT(1H ,*          VGG     *,3X,*ID*,6X,*GMT/GM*,
     1        9X,*N.F.*,7X,*FT*,7X,*WOO    GAIN*,/)
      GO TO 325
457   WRITE (5,477)
      WRITE (7,477)
477   FORMAT(1H ,*          VDD     *,3X,*ID*,6X,*GMT/GM*,
     1        9X,*N.F.*,7X,*FT*,7X,*WOO    GAIN*,/)
      GO TO 325
458   WRITE (5,478)
      WRITE (7,478)
478   FORMAT(1H ,*          RSG     *,3X,*ID*,6X,*GMT/GM*,
     1        9X,*N.F.*,7X,*FT*,7X,*WOO    GAIN*,/)
      GO TO 325
459   WRITE (5,479)
      WRITE (7,479)
479   FORMAT(1H ,*          RGD     *,3X,*ID*,6X,*GMT/GM*,
     1        9X,*N.F.*,7X,*FT*,7X,*WOO    GAIN*,/)
      GO TO 325
460   WRITE (5,480)
      WRITE (7,480)
480   FORMAT(1H ,*       FREQUENCY*,3X,*ID*,6X,*GMT/GM*,
     1        9X,*N.F.*,7X,*FT*,7X,*WOO    GAIN*,/)
      GO TO 325
461   WRITE (5,481)
      WRITE (7,481)
481   FORMAT(1H ,*          PHI     *,3X,*ID*,6X,*GMT/GM*,
     1        9X,*N.F.*,7X,*FT*,7X,*WOO    GAIN*,/)
      GO TO 325
462   GO TO 382
463   WRITE (5,483)
      WRITE (7,483)
483   FORMAT(1H ,*     GATE RES.  *,3X,*ID*,6X,*GMT/GM*,
     1        9X,*N.F.*,7X,*FT*,7X,*WOO    GAIN*,/)
      GO TO 325
464   DISPLAY*14 IS NOT AN AVAILABLE PARAMETER.  TRY AGAIN.*
      GO TO 312
```

```
465   WRITE(5,485)
      WRITE(7,485)
485   FORMAT(1H ,*  DIFF CONST    *,3X,*ID*,6X,*GMT/GM*,
     1        9X,*M.F.*,7X,*FT*,7X,*WCC    GAIN*,/)
      GO TO 325
      END
```

```
*RAPIDIN
      SUBROUTINE RAPIDIN (IOP)
C
C  THIS SUBROUTINE CAN BE USED INSTEAD OF =VALUES= WHEN THE USER
C  IS FAMILIAR WITH THE PROGRAM
C
      COMMON/CONSTS/ECHARG,AMUO,ESAT,DIELC,BOLTZK,DIFCON,PI
      COMMON/EXTPAR/GL,Z,A,DOPEC,T,VGG,VDD,RPF,RPDF,RPM,ATITLE(7),PHI,F,
     1         IPROFIL,DOPIN(101),DOP(101),DOPB(101),DOP2B(101)
      COMMON/CALC/P,S,GO,AISAT,AID,WGG,SATDEX,ARGU
      COMMON/PAROUT/FMIN,GM,CSG,CGD,CSD,RPI,GL1,GL2,RD,RSOPT,XSOPT
      COMMON/ANCPAR/SSG,SL,DOPES,DOPESG,RSCS,RSHS,RSHG,SGD,DL,
     1                  DOPED,DOPLGD,RSCD,RSHD,IREG,ISYM
504   DISPLAY*ENTER L,Z,A,T,VGG,VDD,RSG,RGD,FGATE,F*
      ACCEPT GL,Z,A,T,VGG,VDD,RPF,RPDR,RFM,F
      GL = GL*1.E-4
      Z = Z*1.E-4
      A = A*1.E-4
      F = F*1.E9
      DISPLAY*DOPEC PROFILE OPTION (0=LIST)≥*
      ACCEPT IPROFIL
      IF (IPROFIL.NE.0) GO TO 509
      DISPLAY*1-  CONSTANT*
      DISPLAY*2-  ARBITRARY*
      DISPLAY*PROFILE OPTION DESIRED≥*
      ACCEPT IPROFIL
509   GO TO (510,520) IPROFIL
510   DISPLAY*DOPEC>*
      ACCEPT DOPEC
      GO TO 576
520   DISPLAY*NUMBER OF VALUES≥*
      ACCEPT NDOP
      DISPLAY*ENTER VALUES IN E15/CC.  START AT GATE METAL.*
      ACCEPT (DOPIN,I=1,NDOP)
      DO 522 I=1,NDOP
522   DOPIN(I) = DOPIN(I)*1.E16
      GO TO 576
576   CALL CHECK (IOP)
      IF (IOP.NE.-2) GO TO 576
      DISPLAY*AN INPUT ERROR PROBABLY OCCURED.  REENTER.*
      IOP = 4
      GO TO 504
```

```
578   DISPLAY*OPTION NUMBER?*
      ACCEPT IOP
      MICP = IOP
      IOP = -1*IOP
      GO TO (581,582,583,584,585,586,587) MICP
581   RETURN
582   CALL OPTION1 (IOP)
      RETURN
563   CALL OPTION2 (IOP)
      RETURN
584   GO TO 578
585   IOP = -1*IOP
      CALL ANCIL(IOP)
      RETURN
586   CALL IVCHAR(IOP)
      RETURN
587   CALL OPTION2(IOP)
      RETURN
      END
```

```
*ANCIL
      SUBROUTINE ANCIL (IOP)
C  THIS SUBROUTINE EVALUATES THE PARASITIC RESISTANCES AND CAPACITANCES
C
      COMMON/CONSTS/ECHARG,AMUO,ESAT,DIELC,BOLTZK,DIFCON,PI
      COMMON/EXTPAR/GL,Z,A,DOPEC,T,VGG,VDD,RPF,RPDR,RPM,ATITLE(7),PHI,F,
     1        IPROFIL,DOPIN(101),DOP(101),DOPB(101),DOP2B(101)
      COMMON/PAROUT/FMIN,GM,CSG,CGD,CSD,RFI,GL1,GL2,RD,RSOPT,XSOPT
      COMMON/ANCPAR/SSG,SL,DOPES,DOPESG,RSCS,RSHS,RSHG,SGD,DL,
     1                DOPED,DOPLGD,RSCD,RSHD,IREG,ISYM
C
      COTH(X) = (EXP(2.*X)+1.)/(EXP(2.*X)-1.)
      RES(X) = -1./(ECHARG*MOBLTY(X,T)*X*A)
C
C  ALL ANCILLARY REGION PARAMETERS HAVE DEFAULT VALUES TO REDUCE
C  THE AMOUNT OF INPUT TIME.
C
C  SOURCE REGION
      IF (IOP.EQ.99) GO TO 650
      DISPLAY*ANCILLARY REGION PARAMETER OPTION?  (0=LIST)*
      ACCEPT IANCOP
      IF (IANCOP.NE.0) GO TO 604
      DISPLAY*          ANCILLARY REGION OPTIONS*
      DISPLAY*  *
      DISPLAY*1-        USE INTERNAL DEFAULT VALUES.*
      DISPLAY*2-        USE DEFAULT VALUES WITH POSSIBLE CHANGES.*
      DISPLAY*3-        USE PRESENT VALUES.*
      DISPLAY*4-        USE PRESENT VALUES WITH SOME CHANGES.*
      DISPLAY*  *
      DISPLAY*NOTE:     ONCE A PARAMETER SET IS GENERATED, IT IS*
      DISPLAY*          RETAINED AND MAY BE MODIFIED AND USED*
      DISPLAY*          THROUGHOUT THE SESSION.*
      DISPLAY*  *
      DISPLAY*ENTER THE DESIRED OPTION*
      ACCEPT IANCOP
604   GO TO (606,606,650,609) IANCOP
606   SL = 20.E-4
      ISSG = 1
      SLD = SL*1.74
      DOPES = 1.E17
      DOPESG = 1.E17
      RSCS = 1.E-4
```

```
      RSHS =.16
C
C  GATE REGION
      RSHG = .0?
      IF (GL.GT.0.) G? TO 60?
      GL = .5E-4
      Z = 2.E-2
      A = .2E-4
      DOPEC = 5.E16
      T = 300.
608   GLD = GL*1.E4
      SSGD = GLD
      SGDD = GLD
      ZD = Z*1.E4
C
C  DRAIN REGION
      DL = SL
      ISGD = 1
      DLD = DL*1.E4
      DOPED = DOPES
      DOPEGD = DOPESG
      RSCD = RSCS
      RSHD = RSHS
C
C  MC IVER EQUATIONS INCLUSION PARAMETER
      IREC = 2
C
C  DOPING PARAMETER ALONG CHANNEL LENGTH
      ISYM = 2
      IF (IANCOP.EQ.1) GO TO 650
      DISPLAY*DISPLAY DEFAULT VALUES?  (1=YES)*
      ACCEPT IPREVUE
      IF (IPREVUE.EQ.1) GO TO 670
609   DISPLAY*TO CHANGE A PARAMETER:*
610   DISPLAY*ENTER NUMBER (0=LIST, 16=NO CHANGE)*
      ACCEPT IPAR
      IFREVUE = 0
      IF (IPAR.EQ.16) GO TO 650
      IF (IPAR.NE.0) GO TO 620
      DISPLAY*    *
      DISPLAY*ANCILLARY REGION PARAMETER LIST*
      DISPLAY*  *
```

```
DISPLAY*      SOURCE REGION*
DISPLAY*SOURCE-GATE SEPARATION (MICRONS)                  1*
DISPLAY*NOTE:  UNLESS CONTACT SEPARATION IS SET, DEFAULT*
DISPLAY*VALUE OF GATE LENGTH IS USED.  AFTER SETTING VALUE,*
DISPLAY*DEFAULT CAN BE RESTORED BY ENTERING NEGATIVE VALUE.*
DISPLAY*SOURCE CONTACT LENGTH (MICRONS)                   2*
DISPLAY*DOPING CONC. OF SOURCE REGION (ATOMS/CC)          3*
DISPLAY*DOPING CONC. OF INTERMEDIATE SOURCE-*
DISPLAY*      GATE REGION (ATOMS/CC)                      4*
DISPLAY*SPECIFIC CONTACT RESISTIVITY (OHM-CM-CM)          5*
DISPLAY*SHEET RESISTANCE OF SOURCE CONTACT*
DISPLAY*      METAL (OHM/SQUARE)                          6*
DISPLAY*  *
DISPLAY*      GATE REGION*
DISPLAY*GATE WIDTH (MICRONS)                              7*
DISPLAY*GATE LENGTH (MICRONS)                             8*
DISPLAY*SHEET RESISTANCE OF GATE CONTACT*
DISPLAY*      METAL (OHM/SQUARE)                          9*
DISPLAY*   *
DISPLAY*      DRAIN REGION*
DISPLAY*GATE-DRAIN SEPARATION (MICRONS)                  10*
DISPLAY*DEFAULT IS CHANGED OR SET AS FOR S-G*
DISPLAY*SEPARATION.*
DISPLAY*DRAIN CONTACT LENGTH (MICRONS)                   11*
DISPLAY*DOPING CONC. OF DRAIN REGION (ATOMS/CC)          12*
DISPLAY*DOPING CONC. OF INTERMEDIATE GATE-*
DISPLAY*      DRAIN REGION (ATOMS/CC)                    13*
DISPLAY*SPECIFIC CONTACT RESISTIVITY (OHM-CM-CM)         14*
DISPLAY*SHEET RESISTANCE OF DRAIN CONTACT*
DISPLAY*      METAL (OHM/SQUARE)                         15*
DISPLAY*  *
DISPLAY*TO STOP MAKING CHANGES TYPE                      16*
DISPLAY*  *
DISPLAY*THE RESISTANCE UNDER THE SOURCE AND*
DISPLAY*DRAIN CONTACTS:*
DISPLAY*  VALUE = . TO IGNORE CONTRIBUTION*
DISPLAY*  VALUE = 2 TO APPROXIMATE CONTRIBUTION*
DISPLAY*           USING MC IVER'S EQUATIONS             17*
DISPLAY*  *
DISPLAY*DOPING CONCENTRATION IN ALL ANCILLARY*
DISPLAY*REGIONS:*
DISPLAY*  VALUE = 1 PROVIDES INDIVIDUAL VALUES*
```

```
      DISPLAY*                FOR EACH REGION*
      DISPLAY*  VALUE = 2 MAKES CONCENTRATION OF ANCILLARY*
      DISPLAY*                THE SAME AS UNDER THE GATE     *
      DISPLAY*  VALUE = 3 MAKES INTERELECTRODE DOPING*
      DISPLAY*                SAME AS FOR GATE REGION.*
      DISPLAY*                CONTACT DOPING MAY BE DIFFERENT  13*
      DISPLAY*  *
      GO TO 610
620   DISPLAY*NEW VALUE>*
      ACCEPT X
      GO TO (631,632,633,634,635,636,637,638,639,640,641,642,
     1       643,644,645,650,647,648) IPAR
631   SSGO = X
      SSG = X*1.E-4
      ISSG = 0
      IF (X.LT.0.) ISSG = 1
      GO TO 610
632   SLO = X
      SL = X*1.E-4
      GO TO 610
633   DOPES = X
      GO TO 610
634   DOPESG = X
      GO TO 610
635   RSCS = X
      GO TO 610
636   RSHS = X
      GO TO 610
637   ZO = X
      Z = X*1.E-4
      GO TO 610
638   GLO = X
      GL = X*1.E-4
      GO TO 610
639   RSHG = X
      GO TO 610
640   SGDO = X
      SGD = X*1.E-4
      ISGD =0
      IF (X.LT.0.) ISGD = 1
      GO TO 610
641   DLO = X
```

```
      DL = X*1.E-4
      GO TO 610
642   DOPED = Y
      GO TO 610
643   DOPEGD = Y
      GO TO 610
644   RSCD = X
      GO TO 610
645   RSHD = Y
      GO TO 610
647   IF (INT(X).EQ.1) IREG = 1
      IF (INT(X).EQ.2) IREG = 2
      GO TO 610
648   ISYM = INT(X)
      GO TO 610
C
C  PARASITIC RESISTANCE CALCULATIONS
650   IF (ISSG.EQ.1) SSG = GL
      IF (ISGD.EQ.1) SGD = GL
      IF (ISYM.EQ.1) GO TO 652
      IF (ISYM.EQ.2) GO TO 651
      DOPES = DOPEC
      DOPED = DOPEC
651   DOPESG = DOPEC
      DOPEGD = DOPEC
652   RPM = RSHG*Z/2./GL
      IF (IREG.EQ.2) GO TO 654
      DOPESG = DOPEC
      RPF = RES(DOPESG)*SSG/Z
      GO TO 656
654   ACOTH = SQRT(RES(DOPES)/RSCS)*SL
      IF (ACOTH.GT.370.) GO TO 694
      RPF = COTH(ACOTH)*SQRT(RES(DOPES)*RSCS)/Z
     1        +RES(DOPESG)*SSG/Z+RSHS*Z/2./SL
656   IF (IREG.EQ.2) GO TO 658
      DOPEGD = DOPEC
      RPDR = RES(DOPEGD)*SGD/Z
      GO TO 660
658   ACOTH = SQRT(RES(DOPED)/RSCD)*DL
      IF (ACOTH.GT.370.) GO TO 694
      RPDR = COTH(ACOTH)*SQRT(RES(DOPED)*RSCD)/Z
     1        +RES(DOPEGD)*SGD/Z+RSHD*Z/2./DL
```

```
C
C  CAPACITANCE CALCULATIONS
660    AMOD1 = SQRT(SSD/(SGD+GL))
       AMOD2 = SQRT(1.-AMOD1*AMOD1)
       CGD = 13.5*DIELC/12.5*Z*ELLIP(AMOD2)/ELLIP(AMOD1)
       SSD = SSG+GL+SGD
       AMOD3 = SQRT((2.*SL+SSD)*SSD/(SL+SSD)**2)
       AMOD4 = SQRT(1.-AMOD3*AMOD3)
       CSD = 13.5*DIELC/12.5*Z*ELLIP(AMOD4)/ELLIP(AMOD3)
       IF (IOP.EQ.99) RETURN
       DISPLAY*DISPLAY INPUT AND PARASITIC VALUES (1), PARASITICS*
       DISPLAY*ONLY (2) OR NO LISTS (3)?*
       ACCEPT IWANT
       IUSE = 0
       GO TO (670,684,690) IWANT
670    WRITE (5,672)
       WRITE(7,672)
672    FORMAT (1H1,/,1H ,*INPUT VALUES FOR ANCILLARY REGION ANALYSIS*,
     1          /,39X,*SOURCE*,6X,*GATE*,5X,*DRAIN*,/)
674    WRITE(5,676) SLD,GLD,DLC,ZD,ZD,ZD
       WRITE(7,676) SLD,GLD,DLC,ZD,ZD,ZD
676    FORMAT(1H ,9X,*CONTACT LENGTH (MICRONS):*,3F10.2,/,
     1        1H ,10X,*CONTACT WIDTH (MICRONS):*,3F10.2)
       WRITE(5,678) SSGD,SGDD
       WRITE(7,678) SSGD,SGDD
678    FORMAT(1H ,3X,*SEPARATION FROM GATE (MICRONS):*,F10.2,
     1        F20.2)
       WRITE(5,680) DOPES,DOPEC,DOPED,DOPESG,DOPEGD
       WRITE(7,680) DOPES,DOPEC,DOPED,DOPESG,DOPEGD
680    FORMAT(1H ,7X,*DOPING UNDER CONTACT (/CC):*,3E10.2,/,
     1        1H ,4X,*DOPING BETWEEN CONTACTS (/CC):*,E10.2,
     2        F20.2)
       WRITE(5,682) RSCS,RSCD,RSHS,RSHG,RSHD
       WRITE(7,682) RSCS,RSCD,RSHS,RSHG,RSHD
682    FORMAT(1H ,2X,*SPECIFIC CONTACT RES. (OHM-CM2):*,E10.2,
     1        F20.2,/,1H ,2X,*SHEET RES. OF CONTACT (OHM/SQ.):*,
     2        3F10.2,/)
       IF (IPREVUE.NE.1) GO TO 684
       IPREVUE = 0
       GO TO 690
684    WRITE (5,686)
       WRITE(7,686)
```

```
686   FORMAT(1H ,*PARASITIC RESISTANCE (OHM) AND CAPACITANCE (PF) *
     1         *OF DEVICE*,/)
      CSDO = CSD*1.E12
      CGDO = CGD*1.E12
      WRITE(5,688) RPF,CSDO,RPM,CGDO,RPDR
      WRITE(7,688) RPF,CSDO,RPM,CGDO,RPDR
688   FORMAT(1H ,5X,*S RES (RF)*, F10.2,10X,*S-D CAP*,
     1         F10.4,/,1H ,5X,*G RES (RM)*,F10.2,10X,
     2         *G-D CAP*,F10.4,/,1H ,4X,*D RES (RDR)*,
     3         F10.2,//)
      IF (IOP.NE.5) GO TO 690
      DISPLAY*NEXT, MAKE A REVISED RUN (-1), CHANGE OPTION (0)*
      DISPLAY*OR CONCLUDE SESSION (1)?*
      ACCEPT IWANT
      IF (IWANT) 610,690,692
690   RETURN
692   IOP = 0
      RETURN
694   DISPLAY*SOURCE RESISTANCE CANNOT BE CALCULATED.  THE CONT.*
      DISPLAY*RESISTANCE, DOPING CONC, OR CHANNEL DEPTH MUST BE*
      DISPLAY*INCREASED.*
      GO TO 610
      END
```

```
*ELLIP
      FUNCTION ELLIP(AMOD)
C
C  FUNCTION TO EVALUATE THE COMPLETE ELLIPTICAL INTEGRAL OF THE
C  FIRST KIND
      ELLIP = 0.
      DX = 3.14159/2./30.
      DO 695 I=1,30
      AI = FLOAT(I)
      X = (AI-.5)*DX
695   ELLIP = ELLIP+DX/SQRT(1.-AMOD*SIN(X)**2)
      RETURN
      END
```

```
*IVCHAR
      SUBROUTINE IVCHAR (IOP)
C
C  THIS SUBROUTINE CALCULATES DRAIN CURRENT VS. DRAIN VOLTAGE
C
      COMMON/CONSTS/ECHARG,AMLO,ESAT,DIELC,BOLTZK,DIFCON,PI
      COMMON/EXTPAR/GL,Z,A,DOPEC,T,VGG,VDD,RPF,RPOR,RPM,ATITLE(7),PHI,F,
     1       IPROFIL,DOPIN(101),DUP(101),DOPB(101),DOP2B(101)
      COMMON/CALC/P,S,CO,AISAT,AID,WOO,SATDEX,ARGU
      COMMON/PAROUT/FMIN,GM,CSG,CGD,CSD,RPI,GL1,GL2,RD,RSOPT,XSOFT
      COMMON/TOPLT/FX(50),FY(50,10),FG(50),NFT,NLN
      COMMON/ANCPAR/SSG,SL,DOPES,DOPESG,RSCS,RSHS,RSHG,SGD,DL,
     1              DOPED,DOPEGD,RSCD,RSHD,IREG,ISYM
      DIMENSION VAROUT(10),VPIND(10)
704   DISPLAY*CHOOSE:  INFO. (0), REGULAR (1), HIGH SPEED (2)*
      ACCEPT ISPEED
      IF (ISPEED.NE.0) GO TO 706
      DISPLAY*IVCHAR MAY BE USED IN TWO MODES.*
      DISPLAY*  *
      DISPLAY*1-  REGULAR.  CALCULATES 29 DATA POINTS OVER A*
      DISPLAY*    RANGE OF 3, 6 OR SOME OTHER VALUE OF VDD.*
      DISPLAY*    YOU CHOOSE WHETHER THE CURVES ARE OUTPUT AS*
      DISPLAY*    TABLES, PLOTS OR BOTH.*
      DISPLAY*2-  HIGH SPEED.  CALCULATES 6 DATA POINTS (1-6V)*
      DISPLAY*    WITH OUTPUT AS TABLES.  THIS MODE IS USEFUL*
      DISPLAY*    WHEN ADJUSTING PARAMETERS TO FIT EMPERICAL*
      DISPLAY*    DATA.*
      DISPLAY*  *
      GO TO 704
706   DISPLAY*ENTER A DESCRIPTIVE HEADING FOR THIS RUN.*
      READ(4,708) ATITLE
708   FORMAT (7A10)
      IF (IOP.GT.0) CALL VALUES(IOP)
      IF (IOP.LT.0) IOP = -1*IOP
      IF (VDD.GT.-90.) GO TO 711
      VDD = -W00
710   IOP = 6
711   DISPLAY*CALCULATE PARASITICS?  (0=NO 1=TRW 2=FUKUI)*
      ACCEPT IPARAS
      IF (IPARAS.EQ.1) CALL ANCIL(IOP)
      IF (IPARAS.EQ.2) CALL ANCIL2(IOP)
712   DISPLAY*THIS OPTION COMPUTES DRAIN CURRENT VS. DRAIN BIAS.*
```

```
      DISPLAY*CHOOSE A MAXIMUM VDD OF 3V, 6V OR ANOTHER VALUE.*
      ACCEPT VDDMAX
714   DISPLAY*YOU MAY ALSO VARY ANOTHER PARAMETER.*
      DISPLAY*NUMBER OF PARAMETER?  ( = LIST, 6 = VGG)*
      ACCEPT IWANT
      IF (IWANT.NE.0) GO TO 718
      DISPLAY*GATE LENGTH            1*
      DISPLAY*GATE WIDTH             2*
      DISPLAY*CHANNEL DEPTH          3*
      DISPLAY*DOPING DENSITY         4*
      DISPLAY*DEVICE TEMP            5*
      DISPLAY*GATE BIAS              6*
      DISPLAY*DRAIN BIAS             7*
      DISPLAY*RSG                    8*
      DISPLAY*RGD                    9*
      DISPLAY*SIGNAL FREQ           10*
      DISPLAY*BUILT-IN POTENTIAL    11*
      DISPLAY*NO 3RD VARIABLE       12*
      DISPLAY*GATE RESISTANCE       13*
      DISPLAY*  *
715   DISPLAY*ENTER THE NUMBER OF THE PARAMETER YOU WANT TO VARY.*
      ACCEPT IWANT
718   IF (IWANT.NE.12) GO TO 720
      J = 1
      GO TO 724
720   DISPLAY*INITIAL AND FINAL VALUES OF PARAMETER*
      DISPLAY*AND INTERVAL BETWEEN CALCULATIONS?*
      ACCEPT VAR1,VAR2,VINT
      IF (VAR1.GT.VAR2) VINT = (-1.)*ABS(VINT)
      NLN = INT((VAR2-VAR1)/VINT)+1
      J = 0
      DISPLAY*ENTER X AND Y WHERE RGD = X + Y VGG*
      ACCEPT RGDD,RGDC
C
C  LOOP THROUGH VALUES OF CHOSEN PARAMETER
C
      DO 738 J1=1,NLN
      IFR = J1
      VAR = VAR1+(FLOAT(J1)-1.)*VINT
      J = J+1
      VAROUT(J) = VAR
      GO TO (771,772,773,774,775,776,777,778,779,780,781,782,783)IWANT
```

```
724   IERR = 0
      IF (IWANT.NE.9) RPDR = RGDL-VGS*RGDC
      CALL VPCALC(IERR,VP)
      IF (IERR.NE.99) GO TO 726
      J = J-1
      GO TO 738
726   VPIND(J) = VP-AID*(RPF+RPDR)
      IF (ISPEED.EQ.2) GO TO 670
      NPT = 22
C
C  LOOP THROUGH VALUES OF VDD
C
      DO 736 I=1,NPT
      IF (I.LT.20) VDD = .1*FLOAT(I-1)*VDDMAX/6.
      IF (I.GT.20) VDD = .5*FLOAT(I-17)*VDDMAX/6.
729   IF (VDD.LT.VPIND(J)) GO TO 732
      IERR = 0
      CALL PCALC (IERR)
      IF (IERR.NE.99) GO TO 734
      DISPLAY*P NOT CALCULATED AT VDD =*,VDD,*.THE SATURATED REGION.*
730   DISPLAY*VGS =*,VGS,*WHICH MAY BE TOO NEGATIVE.*
      J = J-1
      GO TO 738
732   IERR = 0
      CALL DCALC(IERR)
      IF (IERR.NE.99) GO TO 734
      DISPLAY*ID NOT CALCULATED AT VDD =*,VDD,*,THE UNSATURATED REGION.*
      GO TO 730
734   FX(I) = VDD
736   FY(I,J) = -1.*AID*1.E3
738   CONTINUE
      IF (ISPEED.EQ.2) GO TO 760
C
C  BEGIN OUTPUT SELECTION AND OUTPUT
C
      NLN = J
      WRITE(5,740) J
740   FORMAT(I10,* CURVES HAVE BEEN GENERATED.*)
      IF (J.EQ.0) GO TO 760
742   DISPLAY*DISPLAY I-V DATA?  (1=YES)*
      ACCEPT ITABLE
      CALL VALUES2(IDP)
```

```
      IF (ITABLE.EQ.0) GO TO 758
743   WRITE (5,744)
      WRITE (7,744)
744   FORMAT(1H ,//,10X,*FET DC CHARACTERISTICS*,/)
      DO 756 J=1,NUM
      DISPLAY*  *
      GO TO (851,852,853,854,855,856,857,858,859,860,861,862,863)IWANT
746   WRITE (5,748)
      WRITE(7,748)
748   FORMAT(1H ,8X,*VDD (V)*,6X,*DRAIN CURRENT (MA X -1)*,/)
      IF (ISPEED.EQ.2) GO TO 672
      DO 750 I=1,NET
750   WRITE (5,752) FX(I),FY(I,J)
      WRITE (7,752) FX(I),FY(I,J)
752   FORMAT(1H ,5X,F10.3,5X,F10.3)
756   CONTINUE
      DISPLAY* *
758   DISPLAY*  *
      DISPLAY*DO YOU WANT A PLOT OF THE I-V CURVES? (1,0)*
      ACCEPT IPLOT
      IF (IPLOT.EQ.0) GO TO 760
      CALL FETPLOT (IOP,IWANT,ATITLE)
C
C  END OF OUTPUT SECTION
C
760   WRITE(5,762)
762   FORMAT (//,*NEXT, MAKE A REVISED RUN (-1), CHANGE OPTION (0)*,
     1        /,*OR CONCLUDE SESSION (1)?*)
      ACCEPT IWANT
      IF (IWANT) 764,766,768
764   DISPLAY*FIRST RESET ANY VALUES.*
      CALL NEWVAL
      CALL CHECK(IOP)
      DISPLAY*ENTER ANOTHER DESCRIPTIVE TITLE*
      READ (4,708) ATITLE
      GO TO 715
766   RETURN
768   IOP = 0
      RETURN
771   GL = VAR*1.E-4
      GO TO 790
772   Z = VAR*1.E-4
```

```
      GO TO 799
773   A = VAR*1.E-4
      GO TO 799
774   DOPLC = VAR
      GO TO 799
775   T = VAR
      GO TO 799
776   VGG =VAR
      GO TO 724
777   VDD = VAR
      GO TO 724
778   RPF = VAR
      GO TO 724
779   RSDF = VAR
      GO TO 724
780   F = VAR*1.E9
      GO TO 724
781   PHI = VAR
      GO TO 798
782   GO TO 712
783   RPM = VAR
      GO TO 724
790   IFLAG = -1
      CALL CHECK (IFLAG)
791   IF (IFLAG.EQ.-2) WRITE(5,792) VAR
792   FORMAT (F15.2,10X,*WCC > PHI*)
      IREVIZ = 99
      IF (IPARAS.EQ.1) CALL ANCIL(IREVIZ)
      IF (IPARAS.EQ.2) CALL ANCIL2(IREVIZ)
      GO TO 724
798   IPHI = INT(PHI*1000.)
      CALL CHECK (IPHI)
      GO TO 791
851   WRITE(5,881) VAROUT(J)
      WRITE(7,881) VAROUT(J)
      GO TO 746
852   WRITE(5,882) VAROUT(J)
      WRITE(7,882) VAROUT(J)
      GO TO 746
853   WRITE(5,883) VAROUT(J)
      WRITE(7,883) VAROUT(J)
      GO TO 746
```

```
854   WRITE(5,884) VAROUT(J)
      WRITE(7,884) VAROUT(J)
      GO TO 746
855   WRITE(5,885) VAROUT(J)
      WRITE(7,885) VAROUT(J)
      GO TO 746
856   WRITE(5,886) VAROUT(J),VPIND(J)
      WRITE(7,886) VAROUT(J),VPIND(J)
      GO TO 746
857   WRITE(5,887) VAROUT(J)
      WRITE(7,887) VAROUT(J)
      GO TO 746
858   WRITE(5,888) VAROUT(J)
      WRITE(7,888) VAROUT(J)
      GO TO 746
859   WRITE(5,889) VAROUT(J)
      WRITE(7,889) VAROUT(J)
      GO TO 746
860   WRITE(5,890) VAROUT(J)
      WRITE(7,890) VAROUT(J)
      GO TO 746
861   WRITE(5,891) VAROUT(J)
      WRITE(7,891) VAROUT(J)
      GO TO 746
862   GO TO 746
863   WRITE(5,893) VAROUT(J)
      WRITE(7,893) VAROUT(J)
      GO TO 746
C
C  THIS SECTION IS USED FOR THE HIGH SPEED CALCULATIONS
C
870   IF (IPP.EQ.1) CALL VALUES2(IOP)
      WRITE(5,871) RPF,RPDR,RPM
      WRITE(7,871) RPF,RPDR,RPM
871   FORMAT(1H ,*PSC =*,F6.1,5X,*RGD =*,F6.1,5X,*RGATE =*,F5.1)
      GO TO (851,852,853,854,855,856,857,858,859,360,861,862,863)IWANT
872   DO 876 I=1,6
      VDD = FLOAT(I)*VDDMAX/6.
      IERR = 0
      IF (VDD.LE.VPIND(J)) CALL DCALC(IERR)
      IF (VDD.GT.VPIND(J)) CALL PCALC(IERR)
      IF (IERR.EQ.0) GO TO 874
```

```
      DISPLAY*IF NOT FOUND AT VDD =*,VDD
      GO TO 876
874   AIDD = -AID*1.E3
      WRITE (5,752) VDD,AIDD
      WRITE (7,752) VDD,AIDD
C
C  AFTER LAST DC POINT, N.F. CALCULATED AT THAT BIAS
C
      IF (I.LT.6) GO TO 876
      IERR = 0
      CALL PCALC (IERR)
      IF (IERR.EQ.-1) IUSEC2 = 1
      IF (IERR.EQ.99) GO TO 876
      ISMOKE = 0
      IF (IERR.NE.-1) CALL CRUNCH(ISMOKE)
      IF (IERR.EQ.-1) CALL CRUNCH2(ISMOKE)
      AISATO = AISAT*1.E3
      AIDO = AID*1.E3
      GMO = GM*1.E3
      GMTERMO = GMO/(1.+GM*RPF)
      IF (ISMOKE.EQ.99) GO TO 334
      GANBWD = GM/2./PI/CSG/1.E9
C
C  GAIN CALCULATED IS MAX AVAILABLE POWER GAIN FOR THE PROPERLY
C  MATCHED DEVICE (MATCHED FOR OPTIMUM NOISE FIGURE).  THEREFORE
C  IT IS THE ASSOCIATED GAIN IF THE DEVICE IS STABLE.  OTHERWISE
C  IT IS THE MAXIMUM STABLE GAIN.
C
      IF (IPARAS.EQ.1) GO TO 332
C
C  IF ANCIL IS NOT CALLED...CGD AND CSD CALCULATED.  STOGRAT IS THE
C  RATIO OF SOURCE CONTACT LENGTH TO GATE LENGTH.  INTERELECTRODE
C  DISTANCES EQUAL GATE LENGTH.
C
      STOGRAT = 20.
      CGD = 13.E/12.E*DIELC*Z
      AMOD3 = SQRT((8.+4.*STOGRAT)/(3.+STOGRAT)**2)
      AMOD4 = SQRT(1.-AMOD3*AMOD3)
      CSD = CGD*ELLIP(AMOD4)/ELLIP(AMOD3)
332   CALL SPAR(ITF,GAIN)
      FG(I) = GAIN
334   FY(I,1) = FMIN
```

```
      IF (IWANT.NE.4) GO TO 336
      VAR = VAR*1.E-17
336   IF (IERR.EQ.-1) GO TO 338
C
C  NORMAL OUTPUT
C
      WRITE (5,340) GMTERMO,GMO,FMIN,GANBWO,WOO,GAIN
      WRITE (7,340) GMTERMO,GMO,FMIN,GANBWO,WOO,GAIN
      GO TO 876
C
C  NORMAL OUTPUT WITH * TO DENOTE CRUNCH2 USED
C
338   WRITE (5,342) GMTERMO,GMO,FMIN,GANBWO,WOO,GAIN
      WRITE (7,342) GMTERMO,GMO,FMIN,GANBWO,WOO,GAIN
340   FORMAT (1H ,20X,F8.2,*/*,F5.2,F11.4,F9.2,F10.2,F7.2)
342   FORMAT(1H ,1H*,19X,F8.2,*/*,F5.2,F11.4,F9.2,F10.2,F7.2)
C
C  END OF N.F. CALCULATION
C
876   CONTINUE
      DISPLAY*CONTINUE?  (1=YES)*
      ACCEPT IGOON
      IF (IGOON.EQ.1) GO TO 736
      GO TO 760
C
C  END OF HIGH SPEED CALCULATION SECTION
C
881   FORMAT(1H ,*GATE LENGTH =*,F6.2,* MICRONS*)
882   FORMAT(1H ,*GATE WIDTH =*,F6.2,* MICRONS*)
883   FORMAT(1H ,*CHANNEL DEPTH =*,F6.3,* MICRONS*)
884   FORMAT(1H ,*DOPING DENSITY =*,E10.2,* ATOMS/CC*)
885   FORMAT(1H ,*DEVICE TEMPERATURE =*,F6.2,* K*)
886   FORMAT(1H ,*VGG =*,F6.2,* V.  VPINCH = VSD AT VDD =*,F7.3,* V*)
887   FORMAT(1H ,*DRAIN BIAS =*,F6.3,* V*)
888   FORMAT(1H ,*S-G RESISTANCE =*,F6.2,* OHM*)
889   FORMAT(1H ,*G-D RESISTANCE =*,F6.2,* OHM*)
890   FORMAT(1H ,*FREQUENCY =*,F6.2,* GHZ*)
891   FORMAT(1H ,*BUILT-IN POTENTIAL =*,F6.2,* V*)
893   FORMAT(1H ,*GATE METALIZATION RESISTANCE =*,F7.3,* OHM*)
      END
```

```
*NEWVAL
      SUBROUTINE NEWVAL
C
C  THIS SUBROUTINE IS USED TO CHANGE THE VALUE OF A PARAMETER
C  AFTER THE PROGRAM IS BEGUN
C
      COMMON/CONSTS/ECHARG,AMUO,ESAT,DIELC,BOLTZK,DIFCON,PI
      COMMON/EXTRAP/GL,Z,A,DOPEC,T,VGG,VDD,RPF,FPDK,R2M,ATITLE(7),PHI,F,
     1       IPROFIL,DOPIN(101),DOP(101),DOPB(101),DOP2B(101)
      COMMON/PAROUT/FMIN,GM,CSG,CGD,CSD,RFI,GL1,GL2,RD,RDOPT,XSOPT
      DISPLAY*NUMBER OF PARAMETER TO BE CHANGED?(0=LIST, 12=NO CHANGES)*
906   ACCEPT IWANT
      IF (IWANT.LE.15) GO TO 907
      DISPLAY*VALUE*,IWANT,*IS NOT POSSIBLE.  TRY AGAIN*
      GO TO 906
907   IF (IWANT.EQ.0) GO TO 910
      IF (IWANT.EQ.12) RETURN
      IF (IWANT.EQ.14) GO TO 934
      DISPLAY*NEW VALUE?*
      ACCEPT X
908   GO TO (921,922,923,924,925,926,927,928,929,930,931,932,933,
     1       934,935) IWANT
910   WRITE (5,912)
912   FORMAT (//)
      DISPLAY*GATE LENGTH            1*
      DISPLAY*GATE WIDTH             2*
      DISPLAY*CHANNEL DEPTH          3*
      DISPLAY*DOPING DENSITY         4*
      DISPLAY*DEVICE TEMP            5*
      DISPLAY*GATE BIAS              6*
      DISPLAY*DRAIN BIAS             7*
      DISPLAY*RSG                    8*
      DISPLAY*RGD                    9*
      DISPLAY*SIGNAL FREQ           10*
      DISPLAY*BUILT-IN POTENTIAL    11*
      DISPLAY*PHI IS NORMALLY CALCULATED INTERNALLY.  IT*
      DISPLAY*IS POSSIBLE TO VARY PHI USING OPTION 3.*
      DISPLAY*STOP CHANGES          12*
      DISPLAY*GATE RESISTANCE       13*
      DISPLAY*CHANGE AN ANCILLARY*
      DISPLAY*REGION PARAMETER      14*
916   WRITE(5,912)
```

```
      DISPLAY*HIGH FIELD DIFFUSION CONSTANT     15*
      DISPLAY*ENTER THE NUMBER OF THE PARAMETER YOU WISH TO*
      DISPLAY*CHANGE.*
      GO TO 916
921   GL = X*1.E-4
      GO TO 950
922   Z = X*1.E-4
      GO TO 950
923   A = X*1.E-4
      GO TO 950
924   DOPEC = X
      GO TO 950
925   T =X
      GO TO 950
926   VGG = X
      IF (VGG.LT.0.) GO TO 950
      DISPLAY*NOTE.....VGG IS NORMALLY NEGATIVE.  YOU MAY WISH*
      DISPLAY*TO CHANGE THE VALUE YOU JUST ENTERED.*
      GO TO 950
927   VDD = X
      GO TO 950
928   REF = X
      GO TO 950
929   RPDR = X
      GO TO 950
930   F = X*1.E9
      GO TO 950
931   PHI = X
      GO TO 950
932   RETURN
933   RPM = X
      GO TO 950
934   CALL ANCIL(IOP)
      GO TO 950
935   DIFCON = X
      GO TO 950
950   DISPLAY*NEXT PARAMETER?  (12=NO MORE CHANGES)*
      ACCEPT IWANT
      GO TO 907
      END
```

```
C
C   SETTING VALUES (IOP)
C
C   THIS SUBROUTINE HAS TWO SECTIONS. THE FIRST SECTION IS USED
C   TO INPUT INITIAL VALUES OF FET PARAMETERS. THE SECOND SECTION
C   WRITES THE INITIAL VALUES OUT. IF IOP=99, ONLY THE OUTPUT
C   SECTION IS USED.
C
      COMMON/CONSTS/ECHARG,AMUO,VSAT,DIELC,BOLTZK,DIELCN,PI
      COMMON/FETCHR/GL,Z,A,DOPEC,T,VGG,VDD,RSF,RDUR,RDA,ATITL(7),PHI,F,
     1        TPROFIL,DOPIN(101),UOP(101),DOPB(101),DOP23(101)
      IF (IOP.EQ.99) GO TO 1150
C
C   INPUT SECTION
C
      DISPLAY*ENTER THE REQUESTED VALUES.  IF A PARTICULAR VALUE IS*
      DISPLAY*TO BE CALCULATED THROUGH AN OPTIMIZATION OR ITERATION*
      DISPLAY*ROUTINE, ENTER 0.0 OR AN INITIAL VALUE.*
      DISPLAY* *
1100  DISPLAY*ENTER THE GATE LENGTH, GATE WIDTH, SEMICONDUCTOR*
      DISPLAY*THICKNESS, ALL IN MICRONS.*
      ACCEPT GL, Z, A
      A = A*1.E-4
      Z = Z*1.E-4
      GL = GL*1.E-4
      DISPLAY*THE DOPING CONCENTRATION (DOPEC) THROUGHOUT THE ACTIVE*
      DISPLAY*REGION MAY TAKE MANY FORMS.  IT MAY BE UNIFORM THROUGH-*
      DISPLAY*OUT OR A PARTICULAR VALUE IN EACH REGION SUCH AS ONE*
      DISPLAY*VALUE UNDER THE GATE AND ANOTHER BETWEEN GATE AND SOURCE*
      DISPLAY*CONTACTS.  THIS LATERAL DOPING PROFILE IS DETERMINED IF*
      DISPLAY*THE ANCILLARY REGION ANALYSIS IS INCLUDED.  IN ADDITION,*
      DISPLAY*THE INTRINSIC REGION (THE CHANNEL UNDER THE GATE) MAY*
      DISPLAY*HAVE A VERTICAL DOPING PROFILE.  THE FOLLOWING PROFILES*
      DISPLAY*ARE ALLOWED:*
      DISPLAY*  *
      DISPLAY*1-  CONSTANT:  ONE VALUE OF DOPEC IS USED*
      DISPLAY*2-  ARBITRARY:  N VALUES OF DOPEC ARE INPUT.  THE FIRST*
      DISPLAY*    CORRESPONDS TO THE VALUE AT THE GATE-CHANNEL INTER-*
      DISPLAY*    FACE, THE LAST TO THE CHANNEL-BUFFER OR SUBSTRATE*
      DISPLAY*    INTERFACE.  THE VALUES SHOULD CORRESPOND TO POINTS*
      DISPLAY*    EQUISPACED DOWN THROUGH THE CHANNEL.  UP TO 101*
      DISPLAY*    VALUES MAY BE INPUT.*
```

```
      DISPLAY*  *
      DISPLAY*ENTER NUMBER OF VERTICAL PROFILE DESIRED*
      ACCEPT IPROFIL
      GO TO (1110,1120) IPROFIL
1110  DISPLAY*ENTER CONSTANT DOPEC IN ATOMS/CC*
      ACCEPT DOPEC
      GO TO 1145
1120  DISPLAY*ENTER N, THE NUMBER OF DOPEC VALUES TO BE ENTERED*
      ACCEPT N
      DISPLAY*ENTER THE VALUES OF DOPEC BEGINNING AT THE GATE-CHANNEL*
      DISPLAY*INTERFACE IN UNITS OF E16 ATOMS/CC*
      ACCEPT (DOPIN,I=1,N)
      DO 1124 I=1,N
1124  DOPIN(I) = DOPIN(I)*1.E16
      GO TO 1145
1145  DISPLAY*ENTER DEVICE OPERATING TEMPERATURE IN DEGREES KELVIN*
      ACCEPT T
      DISPLAY*ENTER THE GATE AND DRAIN DC BIAS VOLTAGES.  FOR AN*
      DISPLAY*N DOPED GA-AS FET, THE GATE IS UNBIASED OR NEGATIVE.*
      DISPLAY*IF YOU WANT THE DRAIN VOLTAGE TO EQUAL THE PINCH-OFF*
      DISPLAY*VOLTAGE, LET VDD BE -999.0.*
      ACCEPT VGG, VDD
      DISPLAY*ENTER THE SOURCE TO GATE RESISTANCE, THE GATE TO DRAIN*
      DISPLAY*RESISTANCE AND THE GATE METALIZATION RESISTANCE*
      DISPLAY*(OHMS).  IF AN ANALYSIS OF INTRINIC FET PROPERTIES IS*
      DISPLAY*REQUIRED, THESE VALUES CAN BE SET TO 0.0.*
      ACCEPT RRE, RRDR, RPM
      DISPLAY*ENTER THE SIGNAL FREQUENCY (GHZ).*
      ACCEPT F
      F = F*1.E9
      CALL CHECK (IOP)
      IF (IOP.EQ.2.OR.IOP.EQ.3) RETURN
C
C  OUTPUT SECTION
C
      ENTRY VALUES2
1150  WRITE(5,1152) ATITLE
      WRITE(7,1153) ATITLE
1152  FORMAT(///,7A10,//)
1153  FORMAT(1H1,7A10,//)
      GLO = GL*1.E4
      ZO = Z*1.E4
```

```
      AO = A*1.E4
      FOUT = F*1.E-9
      WRITE(5,1154) CLG, VGG
      WRITE(7,1154) CLG, VGG
 1154 FORMAT(1H ,*GATE LENGTH     =*,F7.2,* MICRONS*,10X,*VGG =*,
     1        F7.2,* V*)
      IF (VDD.LT.-90.) GO TO 1158
      WRITE(5,1156) ZD, VDD
      WRITE(7,1156) ZD, VDD
 1156 FORMAT(1H ,*GATE WIDTH      =*,F7.2,* MICRONS*,10X,*VDD =*,
     1        F7.2,* V*)
      GO TO 1162
 1158 WRITE(5,1160) ZD
      WRITE(7,1160) ZD
 1160 FORMAT(1H ,*GATE WIDTH      =*,F7.2,* MICRONS*,10X,*VDD = VPINCH*)
 1162 WRITE(5,1164)AD, RPF
      WRITE(7,1164)AD, RPF
 1164 FORMAT(1H ,*CHANNEL DEPTH   =*,F7.2,* MICRONS*,10X,*RSG =*,
     1        F7.2,* OHMS*)
      WRITE(5,1166) DOPEC, RPDR
      WRITE(7,1166) DOPEC, RPDR
 1166 FORMAT(1H ,*DOPING DENSITY  =*,E9.2,* ATOMS/CC*, 7X,*RGD =*,
     1        F7.2,* OHMS*)
      WRITE(5,1168) T, RPM
      WRITE(7,1168) T, RPM
 1168 FORMAT(1H ,*DEVICE TEMP     =*,F7.2,* K*,14X,*RGATE =*,
     1        F7.2,* OHM*)
      WRITE(5,1170) FOUT
      WRITE(7,1170) FOUT
 1170 FORMAT(1H ,*FREQ.           =*,F7.2,* GHZ*,//)
      RETURN
      END
```

```
*PCALC
      SUBROUTINE PCALC(IERR)
      COMMON/EXTRAP/SL,Z,A,DEPLC,T,VCC,VDD,RFF,RFDF,RPY,ATITLE(7),PHI,F,
     1        IPROFI,DPRIN(101),DDP(101),DDPP(101),DDP2P(101)
      COMMON/CALC/P,S,SQ,AISAT,AID,WOO,SATDEX,ARGU
      FNS(X) = (VGG+AISAT*(1.-X)*RPF+PHI)/WOO
C
C  FNS(X) = S*S WHEN X = P
      IF (IERR.NE.7) IERR = 0
      APL = (VGG+PHI)/WOO
      IF (APL.GE.0.) GO TO 1220
      IF(IERR.EQ.7) GO TO 1212
      DISPLAY*VGG+PHI > 0.  VGG IS TOO POSITIVE.  THE CHANNEL*
      DISPLAY*IS BEING BIASED POSITIVE BY THE GATE.*
1212  IERR = 99
      RETURN
1220  IF (APL.LT.1.) GO TO 1224
      IF (IERR.EQ.7) GO TO 1212
      DISPLAY*(VGG+PHI)/WOO >1.  THE CHANNEL BELOW THE GATE IS*
      DISPLAY*NOW BIASED BEYOND THE VOLTAGE NECESSARY TO DEPLETE*
      DISPLAY*THE REGION OF CARRIERS.  VGG IS TOO NEGATIVE.*
      GO TO 1212
1224  PL = SQRT(APL)
      PH = 1.-1.E-5
1230  STEP = (PH-PL)/10.
      IF (STEP.GT.1.E-8) GO TO 1240
      IF(IERR.EQ.7) GO TO 1212
      DISPLAY*STEP IS TOO SMALL.  PROGRAM STOPPED BEFORE CONVERGING.*
      DISPLAY*TO P OCCURED.  P=*,P,*CK =*,CK
      IERR =99
      RETURN
1240  DO 1250 I = 1,11
      P = PL+(I-1)*STEP
      SXS = FNS(P)
      F1 = F*P-SXS-2./3.*(P**3-SXS**1.5)
      ASINH = ARGU*(1.+F1/SATDEX/(1.-F))
      IF (ASINH.LT.-740.) GO TO 1270
      CK = VDD+AISAT*(1.-P)*(RPF+RFDR)+WOO*(F*P-SXS-SATDEX*(EXP(ASINH)
     1      -EXP(-ASINH))/2./ARGU)
      IF (ABS(CK).LT.1.E-4) GO TO 1260
      IF (CK.GT.0.) GO TO 1270
1250  CONTINUE
```

```
1260  IF (IERR.EQ.7) GO TO 1212
      DISPLAY*THIS PART OF THE PROGRAM IS NOT REACHED UNLESS THE EQUA-*
      DISPLAY*TIONS HAVE NOT CONVERGED TO A VALUE FOR P IN SUBROUTINE*
      DISPLAY*PCALC.  P =*,P,*CK =*,CK
      IERR = 99
      RETURN
1270  PL = P-STEP
      PH = P
      GO TO 1230
1280  S = SQRT(SXS)
      AID = ATSAT*(1.-P)
      IF (S.GE.P) IERR = -1
      RETURN
      END
```

```
*CRUNCH
      SUBROUTINE CRUNCH(IOF)
      COMMON/CONSTS/ECHARG,AMUO,VSAT,DIELC,BOLTZK,DIFCON,PI
      COMMON/EXTPAR/GL,Z,A,DOPLC,T,VGG,VDD,REF,RPDR,RPM,ATITLE(7),PHI,F,
     1        IPROFIL,DOPIN(101),DDF(101),DDFB(101),DDP2B(101)
      COMMON/CALC/P,S,GO,AISAT,AID,WOO,SATDEX,ARGU
      COMMON/PAROUT/FMIN,GM,CSG,CGD,CSD,RPI,GL1,GL2,RD,RSOPT,XSOPT
      NAMELIST/CAPS/CSG,CGD,CSD,C1,CPAD,ICAPS
      COMPLEX Y11,Y21,ZC,ARG
      FN(N) = P**N-S**N
      CSQ(ARG) = REAL(ARG)**2+AIMAG(ARG)**2
C
C                            CALCULATE
C  ROOM TEMPERATURE DIFFUSION CONSTANT, EMPERICAL CONSTANT
C  LINKING THE ELECTRON TEMPERATURE TO THE ELECTRIC FIELD
      DIFCNO = AMUO*BOLTZK*300./ECHARG
      DEL = -5.56*T/223.+8.67
C
C  EVALUATE THE FUNCTIONS OF PUCEL, HAUS, AND STATZ.  THE LABELS
C  USED IN THIS PROGRAM CORRESPOND TO THOSE USED IN THEIR PAPER.
      F1 = FN(2)-2./3.*FN(3)
C
C  FROM F1, THE LENGTHS OF REGIONS I AND II CAN BE FOUND.
      PP = 1.-P
1318  GL1 = -GL*F1/SATDEX/PP
      GL2 = GL-GL1
      ARGU2 = PI*GL2/2./A
      COSHA2 = (EXP(ARGU2)+EXP(-ARGU2))/2.
      PPP = 2.*P*PP
C
      F2 = 2./3.*FN(3)-.5*FN(4)
      F31 = 16./PI**3*DIFCON/DIFCNO*(SIN(PI/2.*PP)/(PI/2.)/PP)**2
      F32 = (EXP(2.*ARGU2)-4.*EXP(ARGU2)+3.+2.*ARGU2)
      F3 = F32*F31
C
      FG = ((1.-S)*COSHA2-PP)/((PPP-SATDEX*GL1/GL)*COSHA2-PPP)
      FR = ((PPP-SATDEX*GL1/GL)*COSHA2-PPP)/PP
      FO = WOO*FP/AISAT
      FC1 = GL1/F1/A*(FG*(PPP*PPP+2.*F2)/PP-2.*S*(1.-S))
      FC2 = 2.*GL2/A*FG+(1.-2.*P*FG)*(2.*GL*P/A/SATDEX/COSHA2+
     1      (EXP(2.*ARGU2)-1.)/(EXP(2.*ARGU2)+1.))
      FC = FC1+FC2+1.56
```

```
C
1327  GAMA = PP*PP*F3/F1/COSHA2
      CAY = (-FN(2)/2.+FN(4)/6.+S*S+(1.-2.*S/3.)*FN(1))/F1+GAMA*P
      CAYPR = CAY+CL2/CL1*PP
      CAYPRO = CAYPR-GAMA*P
C
      RO = (CAYPR*(CAYPR*FN(2)-4.*(CAYPR+GAMA)*FN(3)/3.)
     1      +(CAYPR*(CAYPR+4.*GAMA)+GAMA*GAMA)/2.*FN(4)
     2      -4.*GAMA*(CAYPR+GAMA)/5.*FN(5)+GAMA*GAMA/3.*FN(6))/F1**3
      RDEL = DEL*(PP/F1)**3*(-2.*(CAYPR-GAMA)**2*(FN(1)+ALOG(PP/(1.-S)))
     1       +GAMA*(2.*CAYPR-GAMA)*FN(2)-2.*GAMA*GAMA/3.*FN(3))
      SO = (CAYPR*(FN(2)-4.*FN(3)/3.+.5*FN(4))
     1      +GAMA*(-2.*FN(3)/3.+FN(4)-2.*FN(5)/5.))/F1/F1
      SDEL = 2.*DEL*(PP/F1)**2*PP
     1       *((CAYPR-GAMA)*(-FN(1)+ALOG((1.-S)/PP))+GAMA*FN(2)/2.)
      PO = (FN(2)-4.*FN(3)/3.+.5*FN(4))/F1
      PDEL = 2.*DEL/F1*PP**3*(-FN(1)+ALOG((1.-S)/PP))
C
      P1 = PP*(PO+PDEL)/F1/FG/GAMA/GAMA
      P2 = PP*GL*F3/SATDEX/FR/FR/FG/A
      R1 = (2.*GL/A/SATDEX/GAMA/FC)**2*(F1/PP)**3*FG*(RO+RDEL)
      R2 = (2.*F1*CAYPRO/FR/FC)**2*(GL/A/SATDEX/PP)**3*FG*F3
      IF (P1.LE.0.OR.R1.LE.0) GO TO 1330
      IF (P2.LE.0.OR.R2.LE.0) GO TO 1330
      IF (RO.LE.0.OR.RDEL.LE.0) GO TO 1330
      IF (PO.LE.0.OR.PDEL.LE.0) GO TO 1330
      IF (SO.LE.0.OR.SDEL.LE.0) GO TO 1330
      GO TO 1340
1330  IF (IOP.EQ.7) GO TO 1348
      DISPLAY*CRUNCH SMOKING+  MODEL BREAK DOWN.*
      GO TO 1344
C
1340  C = ((SO+SDEL)*SQRT(P1*R1/(RO+RDEL)/(PO+PDEL))
     1      +SQRT(P2*R2))/SQRT((P1+P2)*(R1+R2))
      IF (C.LE.1.) GO TO 1350
      IF (IOP.EQ.7) GO TO 1348
      DISPLAY*CORRELATION COEFFICIENT GREATER THAN ONE+  C =*,C
1344  WRITE (6,1346) P,S
1346  FORMAT(*NOISE NOT CALCULATED.  P =*,F10.3,*  S =*,F10.6)
      FMIN = 0.
      GM = 0.
1348  IOP = 99
```

```
      RETURN
C
1350  RAT = SQRT((R1+R2)/(R1+R2))
      CAT = (1.-C*RAT)**2+(1.-C*C)*RAT*RAT
      CAYG = (R1+R2)*CAT
      CAYC = (1.-C*RAT)/CAT
      CAYR = (R1+R2)*(1.-C*C)/CAT
C
C                     FINALLY, CALCULAT
C  SOURCE TO DRAIN CAPACITANCE, TRANSCONDUCTANCE, GAIN-
C  BANDWIDTH PRODUCT, AND MINIMUM NOISE FIGURE AT
C  FREQUENCY F
      CSG = DIELC*Z*FC
      IF (ICAPS.EQ.1) GO TO 1362
C
C  CHANCE TO SET CAPACITOR VALUES
C
      CSGD = CSG*1.E12
      CGDD = CGD*1.E12
      CSDD = CSD*1.E12
      C1D = C1*1.E12
      CPADD = CPAD*1.E12
      WRITE(5,1360) CSGD,CGDD,CSDD,C1D
      WRITE(7,1360) CSGD,CGDD,CSDD,C1D
1360  FORMAT(1H ,*CSG =*,F7.4,4X,*CGD =*,F7.4,4X,*CSD =*,F7.4,4X,
     1         *C1 =*,F7.4,4X,*CPAD =*,7.4)
      DISPLAY*CHANGE ANY VALUE USING =NAME == VALUE IN FARADS*
      READ(4,CAPS)
C
1362  GM = AISAT/WOO*FG
      GANBW = GM/CSG/2./PI
      RPI = 2.E-3*GL/CSG
      FMIN = 1.+2.*F/GANBW*SQRT(CAYG*(CAYR+GM*(RPM+RPF)*T/300.))
     1         +2.*(F/GANBW)**2*CAYG*GM*((RPM+RPF)*T/300.+CAYC*RPI)
      FMIN = 10*ALOG10(FMIN)
C
C  THE FOLLOWING COMPUTES NOISE WITH CGD AND C1 INCLUDED
C
1364  W =2.*PI*F
      Y11 = CMPLX(0.,W*CSG)/CMPLX(1.,W*CSG*RPI)+CMPLX(0.,W*(CGD+C1))
      Y21 = CMPLX(GM,0.)/CMPLX(1.,W*CSG*RPI)-CMPLX(0.,W*CGD)
      GGN = (W*CSG)**2/GM*(R1+R2)
```

```
      GDN = GM*(RI+F2)
      ARG = Y11*SQRT(GDN)/Y21-CMPLX(0.,C*SQRT(GGN))
      GN = CSQ(ARG)+(1.-C*C)*GGN
      RN = RRM+RRE+GDN*(1.-C*C)*GGN/CSQ(Y21)/GN
      ARG = GDN*CONJG(Y11)/CSQ(Y21)+CMPLX(0.,C*SQRT(GGN*GDN))/Y21
      ZC = RRM+RRE+ARG/GN
      RC = REAL(ZC)
      RSOPT = SQRT(RC*RC+RN/GN)
      FMINC = 1.+2.*GN*(RC+RSOPT)
      FMINC = 10.*ALOG10(FMINC)
      WRITE(5,1366) FMINC
      WRITE(7,1366) FMINC
1366  FORMAT(1H ,7X,*NF(WITH CAPS) =*,F6.3,* DB*)
C
C  CALCULATE THE OPTIMUM SOURCE IMPEDANCE FOR LOW NOISE.
C
      SGF = 2.*PI*F*CSG
      Y11 = CMPLX(0.,SGF)/CMPLX(1.,SGF*RPI)
      ZC = RRM+RRE+CAYC/Y11
      GN = CAYG*SGF*SGF/GM
      RN = RRM+RRE+CAYR*(1.+GN/CAYG*RPI*RPI)
      RSOPT = SQRT(REAL(ZC)**2+RN/GN)
      XSOPT = -AIMAG(ZC)
1370  AKFUG = .033
      TGL = GL*1.E4
      TF = F*1.E-9
      TDDPEC = DDPEC*1.E-16
      TA = A*1.E4
      TZ = Z*10.
      T1 = AKFUG*TF*TGL**(5./6.)*(TDDPEC/TA)**(1./6.)
      T2 = T1*SQRT(TZ)
      T3 = SQRT(RRE+RRM)
      T4 = 1.+T2+T3
      FMINF = 10.*ALOG10(T4)
      WRITE(5,1374) FMINF
      WRITE(7,1374) FMINF
1374  FORMAT(1H ,11X,*NF(FUKUI) =*,F6.3,* DB*)
1380  CONTINUE
C  PRINT OUT OF INTERMEDIATE VALUES CONTROLED BY IFRINT
C
      IPRINT = 0
      IF (IPRINT.EQ.0) RETURN
```

```
      WRITE(7,1) F3,FC,FG,FR
1     FORMAT(1H ,/,1H ,*F3 =*,E12.3,4X,*FC =*,F10.3,4X,*FG =*,F10.3
     1       ,4X,*FR =*,F5.3)
      WRITE(7,6) F31,F32,F
6     FORMAT(1H ,*F31 =*,E12.3,4X,*F32 =*,E12.3,4X,*F =*,F8.6)
      WRITE(7,2) PAT,CAT,C
2     FORMAT(1H ,*PAT =*,F10.3,4X,*CAT =*,F10.4,4X,*C =*,F18.14)
      WRITE(7,3) CAYG,CAYR,CAYC
3     FORMAT(1H ,*KG =*,F10.3,4X,*KR =*,F12.8,4X,*KC =*,F10.3)
      WRITE(7,4) R1,R2,F1,F2
4     FORMAT(1H ,*R1 =*,E12.4,4X,*R2 =*,E12.4,4X,*F1 =*,E12.4,4X,
     1       *F2 =*,E12.4)
      PAD = R1+R2
      RAD = R1+R2
      WRITE(7,5) PAD,RAD
5     FORMAT(1H ,*P =*,F10.3,4X,*R =*,F10.3)
      RC = REAL(7C)
      WRITE(5,7) GN,RC,RSQPT
      WRITE(7,7) GN,RC,RSQPT
7     FORMAT(1H ,*GN =*,F10.6,4X,*RC =*,F10.3,4X,*RSQPT =*,F10.3)
      RETURN
      END
```

```
*CHECK
      SUBROUTINE CHECK (IOP)
C
C  THIS SUBROUTINE CHECKS TO MAKE SURE THAT THE GATE BIAS HAS NOT
C  PINCHED OFF THE CHANNEL.
C
      COMMON/CONSTS/ECHARG,AMUO,ESAT,DIELC,BOLTZK,DIFCON,PI
      COMMON/EXTRAP/GL,Z,A,DOPEC,T,VGG,VDD,RPF,RPDF,RPM,ATITLE(7),PHI,F,
     1       IPROFIL,DOPIN(101),DOP(101),DOFE(101),DOP2B(101)
      COMMON/CALC/D,S,GC,AISAT,AID,VDC,SATDLX,ARGU
C
C  SET UP ARRAY WITH VALUES OF DOPING
C
      GO TO (1420,1410) IPROFIL
C
C  FOR ARBITRARY PROFILES, STRAIGHT LINE APPROXIMATIONS ARE USED TO
C  INTERPOLATE BETWEEN POINTS
C
1410  DOPSUM = 0.
      DO 1414 J=1,101
      XJ = (FLOAT(J)-1.)/100.
1412  XI = FLOAT((I-1)/(NDOP-1))
      I2 = I+1
      XI2 = FLOAT((I2-1)/(NDOP-1))
      IF (XJ.LE.XI2) GO TO 1414
      I = I+1
      GO TO 1412
1414  DOP(J) = DOPIN(I)+(XI-XJ)*(DOPIN(I2)-DOPIN(I))/(XI-XI2)
      DOPSUM = DOPSUM+DOP(J)
      DOPEC = DOPSUM/101.
1420  WORKF = .8
      BANGAP = 1.522-5.8E-4*T*T/(T+300)
      DOPINTR = 1.157
      IF (IOP.GT.-10) GO TO 1430
      PHI = FLOAT(IOP)/1000.
      GO TO 1440
C
C  THE FOLLOWING ERROR MAY OCCUR WHEN OPTIMIZING DOPEC
C
1430  IF (DOPEC.GT.DOPINTR) GO TO 1436
      DISPLAY*DOPING CONCENTRATION HAS BECOME UNREALISTICALLY*
      DISPLAY*LOW.*
```

```
      GO TO 1490
1436  ARLOG = DDPEC/DDPINTR
      IF (IPROFIL.NE.1) ARLOG = DDP(1)/DDPINTR
      PHI = -VDPKE+RANGA-/2.+BOLTZK*T/ CHARG*ALOG(ARLOG)
1440  AMU = MOBLTY(DDPEC,T)
      GO = A*ECHARG*AMUO*DDPEC
      AISAT = GO*Z*ESAT
C  CALCULATION OF WOO.  THE VOLTAGE REQUIRED TO PINCH-OFF THE
C  CHANNEL IS WOO-PHI.
C
      GO TO (1450,1460) IPROFIL
1450  WOO = A*GO/2./DIELC/AMUO
      GO TO 1480
C
C  FOR A NON-UNIFORM VERTICAL PROFILE TWO ARRAYS MUST BE GENERATED.
C  THE N-BAR ARRAY..
C
1460  DDPB(1) = 0.
      DO 1462 I=1,7
      I2 = I+1
1462  DDPB(I) = DDPB(I)+(DDP(I)+.5*(DDP(I2)-DDP(I)))*.01
      DO 1464 I=8,101
      CALL DINT(DDP,I,.01,ANS)
1464  DDPB(I) = ANS
C
C  THE N-DOUBLE BAR ARRAY
C
      DDP2B(1) = 0.
      DO 1466 I=1,7
      I2 = I+1
1466  DDP2B(I) = DDP2B(I)+(DDPB(I)+.5*(DDPB(I2)-DDPB(I)))*.01
      DO 1468 I=8,101
      CALL DINT(DDPB,I,.01,ANS)
1468  DDP2B(I) = ANS
      WOO = ECHARG*A*A/DIELC*(DDPB(101)-DDP2B(101))
1480  ARGU = PI*GL/2./A
      SATDEX = ESAT*GL/WOO
      IF (WOO.LT.PHI) RETURN
      IF (IOP.LT.0) GO TO 1490
      DISPLAY*THE BUILT-IN POTENTIAL, PHI, IS MORE NEGATIVE*
      DISPLAY*THAN THE GATE-TO-CHANNEL DEPLETION POTENTIAL,*
      DISPLAY*WOO.  EITHER THE CHANNEL DEPTH MUST BE INCREASED,*
```

```
      DISPLAY*THE DOPING CONCENTRATION INCREASED, OR PHI MADE*
      DISPLAY*LESS NEGATIVE.*
      CALL NEWVAL
      GO TO 1436
1490  IOP = -2
      RETURN
      END
```

```
*MOBLTY
C
      FUNCTION MOBLTY(DOPEC,T)
C
C  FUNCTION DETERMINES THE LOW FIELD MOBILITY OF THE SEMICONDUCTOR
C  USING AN EMPIRICAL RELATION
      MOBLTY = (5.3E+3 -2.5762E-14*DOPEC +5.6107E-32*DOPEC*DOPEC
     1         -6.[illegible]E-50*DOPEC**3 +3.0693E-68*DOPEC**4
     2         -4.4[illegible]E-87*DOPEC**5)*(300./T)**1.5
      RETURN
      END
```

AD-A079 589 TRW DEFENSE AND SPACE SYSTEMS GROUP REDONDO BEACH CA F/G 9/5
GAAS ANALOG INTEGRATED CIRCUITS (GAAS RF-LSI). PHASE I. PROGRES--ETC(U)
AUG 79 N00039-78-C-0305

UNCLASSIFIED NL

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```
*FETPLOT
      SUBROUTINE FETPLOT(IOP,IPAR,ATITLE)
      COMMON/TOPLT/FX(50),FY(50,10),FG(50),NPT,NLN
      DIMENSION ATITLE(4)
      WRITE(3) IOP,IPAR,NPT,NLN
      WRITE(3) ATITLE
      WRITE(3) (FX(I),I=1,NPT)
      DO 1510 J=1,NLN
1510  WRITE(3) (FY(I,J),I=1,NPT)
      IF (IOP.NE.3) RETURN
      DO 1520 J=1,NLN
1520  WRITE(3) (FG(I),I=1,NPT)
      RETURN
      END
```

```
*VPCALC
      SUBROUTINE VPCALC(IERR,VP)
      COMMON/EXTRAF/SL,Z,A,EPSEC,T,VGG,VES,RSF,RROF,RD1,ATITL(7),PHI,F,
     1        TRRRFTI,DDRAIN(101),DDF(101),DDPR(101),DDP2P(101)
      COMMON/CALC/F,P,PP,AISAT,AID,...,SATDEX,ARG
      FNS(X) = (VGG+AISAT*(1.-X)*RPF+PHI)/WOO
C
C  FNS(X) = S*S WHEN X = P
      IERR = 0
      APL = (VGG+PHI)/WOO
      IF (APL.GE.0.) GO TO 1620
      DISPLAY*VGG+PHI > 0.  THE CHANNEL IS BEING BIASED POSITIVE.*
      DISPLAY*THAT IS, VGG IS TOO POSITIVE.*
      IERR = 99
      RETURN
1620  IF (APL.LT.1.) GO TO 1624
      DISPLAY*(VGG+PHI)/WOO > 1.  THE CHANNEL BELOW THE GATE IS*
      DISPLAY*NOW BIASED BEYOND THAT VOLTAGE WHICH DEPLETES THE*
      DISPLAY*CHANNEL OF CARRIERS.  THAT IS, VGG IS TOO*
      DISPLAY*NEGATIVE.*
      IERR = 99
      RETURN
1624  PL = 1.E-6
      PH = 1.-1.E-6
1630  STEP = (PH-PL)/10.
      IF (STEP.GT.1.E-8) GO TO 1640
      DISPLAY*STEP IS TOO SMALL.  PROGRAM STOPPED BEFORE CONVERGENCE*
      DISPLAY*TO P OCCURED.  P=*,P,*CK =*,CK
      IERR =99
      RETURN
1640  DO 1650 I = 1,11
      P = PL+(I-1)*STEP
      SXS = FNS(P)
      F1 = P*P-SXS-2./3.*(F**3-SXS**1.5)
      CK = SATDEX*(1.-P)+F1
      IF (ABS(CK).LT.1.E-4) GO TO 1680
      IF (CK.GT.0.) GO TO 1670
1650  CONTINUE
1660  DISPLAY*THIS PART OF THE PROGRAM IS NOT REACHED UNLESS THE EQUA-*
      DISPLAY*TIONS HAVE NOT CONVERGED TO A VALUE FOR P IN SUBROUTINE*
      DISPLAY*VPCALC.  P =*,P,*CK =*,CK
      IERR = 99
```

```
      RETURN
1670  PL = P-STEP
      PH = P
      GO TO 1630
1680  S = SQRT(SXS)
      AID = AISAT*(1.-P)
      VP = -1.*WOO*(P*P-SXS)
      RETURN
      END
```

```
*NOISE
      SUBROUTINE NOISE(TOP,IUSEC2)
      COMMON/CONSTS/ICHARG,AMCO,ESAT,CILLC,BELTZK,LIFCTN,PI
      COMMON/EXTRAP/CL,Z,A,DOPEC,T,VCC,VDD,RPF,RPDK,RPM,ATITL(7),PHI,F,
     1         IPROFIL,DOPIN(101),DOP(101),DOPP(101),DOP2B(101)
      COMMON/CALC/D,S,GO,AISAT,AID,WOO,SATDEX,APGU
      COMMON/PAROUT/FMIN,GM,CSG,CGD,CSD,RPI,GL1,GL2,RD,RSOPT,XSOPT
      COMMON/ANCPAR/SPG,SL,DOPES,DOPSG,RSCS,RSHS,RSHG,SGD,DL,
     1               DOPED,DOPEGD,RSCD,RSHD,IREG,ISYM
      ICK = -1
      CALL CHECK(ICK)
      IF (ICK.EQ.-2) GO TO 1860
      IERR = 7
      IANC = 99
1840  IF (IERR.EQ.17) CALL ANCIL(IANC)
      IUSEC2 = 0
      CALL PCALC(IERR)
      IF (IERR.EQ.-1) IUSEC2 = 1
      IF (IERR.EQ.99) GO TO 1860
      ISMCKE = 7
      IF (IERR.NE.-1) CALL CRUNCH(ISMOKE)
      IF (IERR.EQ.-1) CALL CRUNCH2(ISMOKE)
      IF (ISMOKE.EQ.99) GO TO 1860
      RETURN
1860  FMIN = 0
      RETURN
      END
```

```
*DCALC
      SUBROUTINE DCALC(IERR)
      COMMON/EXTRAE/CL,Z,A,DOPED,T,VGG,VDD,RFF,RRDR,RPM,ATITLE(7),PHI,F,
     1        IPRPRT,PPRIN(101),DSP(101),DDEP(101),DD2P(101)
      COMMON/CALC/P,S,CO,AISAT,AID,WOO,SATDIX,ARGU
      FNS(X) = (VGG+X*RRF+PHI)/WOO
      FND(X) = (VGG-X*RRDR+PHI-VDD)/WOO
C
C  FNS(X) = S*S WHEN X = ID
C  FND(X) = D*D WHEN X = ID
      IERR = 0
      APL = (VGG+PHI)/WOO
      IF (APL.GE.0.) GO TO 1720
      DISPLAY*VGG+PHI > 0.  ID CANNOT BE CALCULATED.*
      DISPLAY*VGG IS TOO POSITIVE.*
      IERR = 99
      RETURN
1720  IF (APL.LT.1.) GO TO 1724
      DISPLAY*VGG+PHI <WOO.  THE GATE VOLTAGE IS*
      DISPLAY*GREATER THAN THAT REQUIRED TO DEPLETE*
      DISPLAY*THE CHANNEL OF CARRIERS.*
      IERR =99
      RETURN
1724  AIDL = 0.
      AIDH = AISAT
1730  STEP = (AIDH-AIDL)/10.
      IF (ABS(STEP).GT.1.E-8) GO TO 1740
      DISPLAY*STEP IS TOO SMALL.  PROGRAM STOPPED BEFORE CONVERGENCE*
      DISPLAY*TO ID OCCURED.  ID=*,AID,*CK =*,CK
      IERR =99
      RETURN
1740  DO 1750 I = 1,11
      AID = AIDL+(FLOAT(I)-1.)*STEP
      SXS = FNS(AID)
      DXD = FND(AID)
      CK = AID+GO*Z*WOO/GL*(DXD-SXS-2./3.*(DXD**1.5-SXS**1.5))
      IF (ABS(CK).LT.1.E-4) GO TO 1780
      IF (CK.LT.0.) GO TO 1770
1750  CONTINUE
1760  DISPLAY*THIS PART OF THE PROGRAM IS NOT REACHED UNLESS THE EQUA-*
      DISPLAY*TIONS HAVE NOT CONVERGED TO A VALUE FOR P IN SUBROUTINE*
      DISPLAY*DCALC.  ID =*,AID,*CK =*,CK
```

```
      IERR = 99
      RETURN
1770  AIDL = AID-STEP
      AIDH = AID
      GO TO 1730
1780  S = SQRT(SXS)
      RETURN
      END
```

```
*COMPRIP
      SUBROUTINE COMPRPR(IOF)
      COMMON/EXTRAP/GL,7,A,DPREC,T,VCC,VCD,FFF,REDF,REM,ATITL(7),PHI,F,
     1        TPPRETL,DPPIN(1,1),DDP(1,1),DDPH(1,1),DPPPR(1,1)
      COMMON/PARPUT/EMIN,CS,CDG,CCD,CLD,PRI,GL1,GL2,RD,RSOPT,XSOPT
1810  DISPLAY*CHOOSE COMPACT PRINTOUT OPTION (1,2,4,5) OR*
      DISPLAY*0 = INFO.*
      ACCEPT ICOMPOP
      IF (ICOMPOP.NE.0) GO TO 1826
      DISPLAY*  *
      DISPLAY*           COMPACT PRINTOUT OPTIONS*
      DISPLAY*  *
      DISPLAY*1-      PROVIDES S PARAMETERS (MAGN.,ANGLE); STABILITY*
      DISPLAY*        FACTOR (K); WITH S21 IN DB*S.*
      DISPLAY*  *
      DISPLAY*2-      SAME AS 1, PLUS STABILITY CIRCLE SIZE AND*
      DISPLAY*        LOCATION.*
      DISPLAY*  *
      DISPLAY*3-      NOT AVAILABLE.*
      DISPLAY*  *
      DISPLAY*4-      SAME AS 1, PLUS SIMULTANEOUS CONJUGATE MATCH*
      DISPLAY*        AT EACH FREQUENCY.*
      DISPLAY*  *
      DISPLAY*5-      SAME AS 2, BUT PRINTS CONSTANT GAIN CIRCLES*
      DISPLAY*        INSTEAD OF STABILITY CIRCLES.*
      DISPLAY*  *
      DISPLAY*6-10    NOT AVAILABLE.*
      DISPLAY*  *
1820  DISPLAY*CHOOSE AN OPTION.*
      ACCEPT ICOMPOP
1824  IF (ICOMPOP.NE.3.AND.ICOMPOP.LT.6) GO TO 1826
      DISPLAY*OPTION*,ICOMPOP,*NOT AVAILABLE.*
      GO TO 1810
1826  GMO = GY*1.E3
      WRITE(6,1832) RD,GMO
1832  FORMAT(*GEN RR VC 1.E6*,2E10.3)
      WRITE(6,1834)
1834  FORMAT(*CON RR T4 1 2 3 4*)
      CSGC = CSG*1.E12
      WRITE(6,1836) CSGC
1836  FORMAT(*CAP CC SF*,E10.3)
      WRITE(6,1838)
```

```
1838  FORMAT(*CON CC T2 1 2*)
      CSDC = CSD*1.E12
      WRITE(6,1840) CSDC
1840  FORMAT(*CAP CC SF*,E10.3)
      WRITE(6,1842)
1842  FORMAT(*CON DD T2 2 3*)
      WRITE(6,1844) RPI
1844  FORMAT(*RES DD SF*,E10.3)
      WRITE(6,1846)
1846  FORMAT(*CON CC T2 1 4*)
      WRITE(6,1848) RPF
1848  FORMAT(*RES FF SF*,E10.3)
      WRITE(6,1850)
1850  FORMAT(*CON FF T2 4 1*)
      WRITE(6,1852)
1852  FORMAT(*DEF BB T2 2 3*)
      WRITE(6,1854) RPM
1854  FORMAT(*RES AA SF*,E10.3)
      WRITE(6,1856) RPDR
1856  FORMAT(*RES CC SF*,E10.3)
      CSDD = CSD*1.E12
      WRITE(6,1858) CSDD
1858  FORMAT(*CAP DD CA*,E10.3)
      WRITE(6,1860)
1860  FORMAT(*CAX AA DD*)
      WRITE(6,1862) TCOMPOF
1862  FORMAT(*PRT AA S*,I1,* 50*)
      WRITE(6,1864)
1864  FORMAT(*END*)
      DISPLAY*ENTER FREQ. RANGE (GHZ)*
      DISPLAY*(FMIN, FMAX, INTERVAL)*
      ACCEPT FMIN,FMAX,FINT
      FMIN = FMIN*1.E3
      FMAX = FMAX*1.E3
      FINT = FINT*1.E3
      WRITE(6,1870) FMIN,FMAX,FINT
1870  FORMAT(F9.3,2F10.3)
      WRITE(6,1864)
      DISPLAY*COMPACT FILE CREATED WITH NAME =TAPE6=.  MAKE IT*
      DISPLAY*PERMANENT BY USING:*
      DISPLAY*  *
      DISPLAY*REP,TAPE6= NEW FILE NAME*
```

```
DISPLAY*  *
DISPLAY*BEFORE CALLING COMPACT.  DO YOU WANT MORE INFO.*
DISPLAY*ON USING COMPACT?  (1 = YES)*
ACCEPT ITNED
IF (ITNED.NE.1) RETURN
DISPLAY*WHEN BACK IN MACE,REPLACE TAPE6 AS SHOWN ABOVE.*
DISPLAY*THEN RUN COMPACT USING THESE TWO COMMANDS:*
DISPLAY*  *
DISPLAY*GET,COMPACT/AC=COMBLAB*
DISPLAY*COMPACT*
DISPLAY*  *
DISPLAY*THE PROGRAM WILL ASK FOR THE FILE NAME YOU HAVE*
DISPLAY*CHOSEN AND FOR THE MODE OF OPERATION.  SELECT*
DISPLAY*OPTION 1 (ANALYSIS).  *
DISPLAY*NOTE:  IF YOU CALL FOR   PARAMETERS MORE THAN ONCE*
DISPLAY*IN A RUN OF THIS FIT PROGRAM THE SETS OF COMPACT*
DISPLAY*DATA WILL BE WRITTEN CONSECUATIVELY ON TAPE6.  IT*
DISPLAY*WILL THEN BE NECESSARY TO SEPARATE EACH SET AND FORM*
DISPLAY*A DISTINCT PERMANENT FILE WITH EACH SET BEFORE RUNNING*
DISPLAY*COMPACT.*
RETURN
END
```

```
*CRUNCH2
      SUBROUTINE CRUNCH2(IOP)
      COMMON/CONSTS/ECHARG,AMU0,EMAT,C,DIELC,BOLTZK,DIFCON,PI
      COMMON/EXTRAS/GL,Z,A,D,FLC,T,V(C,VT,R,F,FFOR,FFM,ATITLE(7),H1,F,
     1      TOPRT(2,2),IN(2,2),OU(2,2),G(2,2),OUTIN(2,2)
      COMMON/CALC/P,C,GO,AISAT,AID,W00,SATDEX,ARGU
      COMMON/PAROUT/EMIN,GM,CSG,CGD,CID,RPI,GL1,GL2,RD,RSOPT,XSOPT
      COMPLEX Y11,ZC
C
C                              CALCULATE
C  ROOM TEMPERATURE DIFFUSION CONSTANT, EMPERICAL CONSTANT
C  LINKING THE ELECTRON TEMPERATURE TO THE ELECTRIC FIELD
      DIFCNO = AMU0*BOLTZK*300./ECHARG
      DLL = -C.56*T/273.+1.67
C
C  EVALUATE THE FUNCTIONS OF PUCEL, HAUS, AND STATZ FOR THE
C  CASE OF L2 = L.   (P = S).
      PP = 1.-P
1918  GL1 = 0.
      GL2 = GL
      COSHA = (EXP(ARGU)+EXP(-ARGU))/2.
      PPP = 2.*P*PP
C
      F31 = 16./PI**3*DIFCON/DIFCNO*(SIN(PI/2.*PP)/(PI/2.)/PP)**2
      F32 = (EXP(2.*ARGU)-4.*EXP(ARGU)+3.+2.*ARGU)
      F3 = F31*F32
C
      FG = .5/P
      FR = 2.*P*(COSHA-1.)
      RD = W00*FR/AISAT
      FC = GL/A/P+1.56
      P2 = GL*PP*F3/A/SATDEX/FG/FR/FR
      R2 = (2.*GL*FC/A/FC)**2*P2
C
1940  C = 1.
1950  RAT = SQRT(R2/P2)
      CAT = (1.-C*RAT)**2+(1.-C*C)*RAT*RAT
      CAYC = P2*CAT
      CAYC = (1.-C*RAT)/CAT
      CAYR = P2*(1.-C*C)/CAT
C
C                    FINALLY, CALCULATE
```

```
C  SOURCE TO DRAIN CAPACITANCE, TRANSCONDUCTANCE, GAIN-
C  BANDWIDTH PRODUCT, AND MINIMUM NOISE FIGURE AT
C  FREQUENCY F
      CSG = ...*Z*FC
      GM = ATPAT/400*FC
      GANBW = GM/CSG/2./PI
      RFI = 2.E-8*CL/CSG
      FMIN = 1.+2.*F/GANBW*SQRT(CAYG*(CAYR+GM*(RPM+RPF)*T/300.))
     1       +2.*(F/GANBW)**2*CAYG*GM*((RPM+RPF)*T/300.+CAYC*RFI)
      FMIN = 10*ALOG10(FMIN)
C
C  CALCULATE THE OPTIMUM SOURCE IMPEDANCE FOR LOW NOISE.
C
      SGF = 2.*PI*F*CSG
      Y11 = CMPLX(0.,SGF)/CMPLX(1.,SGF*RFI)
      ZC = RPM+RPF+CAYC/Y11
      GN = CAYG*SGF*SGF/GM
      RN = RPM+RPF+CAYR*(1.+GN/CAYG*RFI*RFI)
      RSOPT = SQRT(REAL(ZC)**2+RN/GN)
      XSOPT = -AIMAG(ZC)
1980  CONTINUE
C  PRINT OUT OF INTERMEDIATE VALUES CONTROLLED BY IPRINT
C
      IPPINT = 0
      IF (IPRINT.EQ.0) RETURN
      WRITE(7,1) F3,FC,FG,FR
1     FORMAT(1H ,/,1H ,*F3 =*,E12.3,4X,*FC =*,F10.3,4X,*FG =*,F10.3,
     1       4X,*FR =*,F5.2)
      WRITE(7,6) F31,F32,P
6     FORMAT(1H ,*F31 =*,E12.3,5X,*F32 =*,E12.3,5X,*P =*,F5.6)
      WRITE(7,2) PAT,CAT,C
2     FORMAT(1H ,*PAT =*,F10.3,4X,*CAT =*,F10.4,4X,*C =*,F18.14)
      WRITE(7,3) CAYC,CAYR,CAYC
3     FORMAT(1H ,*KC =*,F10.3,4X,*KR =*,F12.?,4X,*KC =*,F10.3)
      PAD = R?
      RAD = R?
      WRITE(7,5) PAD,PAD
5     FORMAT(1H ,*R =*,F10.3,4X,*R =*,F10.3)
      RC = REAL(ZC)
      WRITE(5,7) GN,RC,RSOPT
      WRITE(7,7) GN,RC,RSOPT
7     FORMAT(1H ,*GN =*,F10.6,4X,*RC =*,F10.3,4X,*RSOPT =*,F10.3)
```

```
*SPAR
      SUBROUTINE SPAR(TDF,GAIN)
C
C  THIS SUBROUTINE CALCULATES THE S-PARAMETERS AND MAX GAIN
C
      COMMON/CONSTS/ECHARG,AMU0,ESAT,DIELC,BOLTZK,DIFCON,PI
      COMMON/EXTPAR/CL,Z,A,DOPLC,T,VGC,VDD,RPF,RPDF,RPM,ATITLE(7),PHI,F,
     1        IPROFIL,DOPIN(101),XOP(101),DOPA(101),DOP2B(101)
      COMMON/PAROUT/EMTA,GM,CSG,CGD,CSD,RPI,CL1,CL2,RD,RSTHI,YSDHT
      COMPLEX Y(3,3),CPX1,YDET,YI,YR,YF,YO,DS,S(2,2),DENOM,ZDEFT,GAMS
     1          ,S22P,GAML,A1,A2,SP(2,2)
C
C  CHECK THAT PARASITIC RESISTANCES HAVE NONZERO VALUES.
C
      IF (RPM.NE.0..AND.RPF.NE.0..AND.RPDR.NE.0.) GO TO 1920
      DISPLAY*GAIN CANNOT BE CALCULATED WITHOUT PARASITIC RESISTANCE*
      GAIN = -99.99
      RETURN
C
1920  Y(1,2) = CMPLX(0.,-2.*PI*F*CGD)
      Y(1,3) = -1./CMPLX(RPI,-1./2./PI/F/CSG)-CMPLX(0.,2.*PI*F*C1)
      Y(1,1) = -Y(1,2)-Y(1,3)+1./RPM
      CPX1 = GM/CMPLX(1.,2.*PI*F*CSG*RPI)
      Y(2,1) = -Y(1,2)-CPX1
      Y(2,2) = Y(1,2)-1./RPDR-1./RD
      Y(2,3) = CPX1+1./RD
      Y(3,1) = CPX1-Y(1,3)
      Y(3,2) = CMPLX(1./RD,0.)
      Y(3,3) = -Y(2,3)+Y(1,3)-1./RPF
C
      YDET = Y(1,1)*(Y(2,2)*Y(3,3)-Y(2,3)*Y(3,2))
     1       -Y(1,2)*(Y(2,1)*Y(3,3)-Y(2,3)*Y(3,1))
     2       +Y(1,3)*(Y(2,1)*Y(3,2)-Y(2,2)*Y(3,1))
C
C  THE Y-PARAMETERS CAN NOW BE CALCULATED
C
1930  YI = 1./RPM*(1.+(Y(2,3)*Y(3,2)-Y(2,2)*Y(3,3))/RPM/YDET)+
     1       CMPLX(0.,2.*PI*F*CPAD)
      YF = (Y(1,3)*Y(2,2)-Y(1,2)*Y(3,2))/RPM/RPDR/YDET
      YF = (Y(3,3)*Y(2,1)-Y(2,3)*Y(3,1))/RPM/RPDR/YDET
      YO = 1./RPDR*(1.+(Y(1,1)*Y(3,3)-Y(1,3)*Y(3,1))/RPDR/YDET)
     1       +CMPLX(0.,2.*PI*F*CSD)
```

```
      AMAGI = 2.*REAL(YT)*REAL(YO)-REAL(YF*YR)
      AMAG2 = AMAGI*AMAGI-CABS(YF*YR)**2
C
C  NEXT THE S-PARAMETERS ARE CALCULATED FOR A 50 OHM LINE.
C
      ZCR = 1./50.
      DS = (ZCR+YI)*(ZCR+YO)-YR*YF
      S(1,1) = ((ZCR-YI)*(ZCR+YO)+YR*YF)/DS
      S(1,2) = -2.*YR*ZCR/DS
      S(2,1) = -2.*YF*ZCR/DS
      S(2,2) = ((ZCR+YI)*(ZCR-YO)+YR*YF)/DS
C
C  THE MAGNITUDES ARE
1940  S11 = CABS(S(1,1))
      S12 = CABS(S(1,2))
      S21 = CABS(S(2,1))
      S22 = CABS(S(2,2))
C
C  THE ANGLES IN DEGREES
1950  S11A = ATAN2(AIMAG(S(1,1)),REAL(S(1,1)))*180./PI
      S12A = ATAN2(AIMAG(S(1,2)),REAL(S(1,2)))*180./PI
      S21A = ATAN2(AIMAG(S(2,1)),REAL(S(2,1)))*180./PI
      S22A = ATAN2(AIMAG(S(2,2)),REAL(S(2,2)))*180./PI
C
C  TO DETERMINE THE GAIN:  1-  S22 IS FOUND WITH THE OPTIMUM SOURCE
C  MATCH.  2-  THE MATCHING LOAD IS DETERMINED.  3-  S PRIME PARAMETERS
C  ARE CALCULATED FOR THE FET WITH ITS MATCHING SECTIONS.  4-  THE
C  STABILITY FACTOR AND GAIN ARE CALCULATED.
C
      ZO = 50.
C
C  OPTIMUM SOURCE IMPEDANCE AND REFLECTION COEFFICIENT
      ZSOPT = CMPLX(RSOPT,XSOPT)
      GAMS = (ZSOPT-ZO)/(ZSOPT+ZO)
C
C  S22 OF FET WITH SOURCE MATCHING AND REFLECTION COEFFICIENT OF LOAD
      S22P = S(2,2)+GAMS*S(1,2)*S(2,1)/(1.-GAMS*S(1,1))
      GAML = CONJG(S22P)
C
C  S-PARAMETERS OF FET AND MATCHING SECTIONS
      DENOM = (1.-GAMS*S(1,1))*(1.-GAML*S(2,2))-GAMS*GAML*S(1,2)*S(2,1)
      A1 = (1.-CONJG(GAMS))*SQRT(1.-CABS(GAMS)**2)/CABS(1.-GAMS)
```

```
      A2 = (1.-CONJG(GAML))*SQRT(1.-CABS(GAML)**2)/CABS(1.-GAML)
      SP(1,1) = CONJG(A1)/A1*((1.-GAML*S(2,2))*(S(1,1)-CONJG(GAMS))+
     1           GAML*S(1,2)*S(2,1))/DENOM
      SP(1,2) = CONJG(A2)/A1*S(1,2)*(1.-CABS(GAMS)**2)/DENOM
      SP(2,1) = CONJG(A1)/A2*S(2,1)*(1.-CABS(GAML)**2)/DENOM
      SP(2,2) = CONJG(A2)/A2*((1.-GAMS*S(1,1))*(S(2,2)-CONJG(GAML))+
     1           GAMS*S(1,2)*S(2,1))/DENOM
C
C  THE STABILITY FACTOR
      STABLE = (1.+CABS(SP(1,1)*SP(2,2)-SP(1,2)*SP(2,1))**2
     1           -CABS(SP(1,1))**2-CABS(SP(2,2))**2)/2.
     2           /CABS(SP(1,2))/CABS(SP(2,1))
C
C  THE ASSOCIATED GAIN IS THE MAXIMUM AVAILABLE POWER GAIN IF THE
C  MATCHED DEVICE IS STABLE (STABLE>1).  IF DEVICE IS UNSTABLE, THE
C  GAIN CALCULATED WILL BE THE MAXIMUM STABLE GAIN.(STABLE=1)
C
      STA = STABLE
      IF (STABLE.LT.1.) STA = 1.
      GAMAX = CABS(SP(2,1)/SP(1,2))*(STA-SQRT(STA*STA-1.))
      IF (GAIN.LT.-90.) GO TO 1960
      GAIN = 10.*ALOG10(GAMAX)
      RETURN
C
C  THIS SECTION WRITES OUT THE S-PARAMETERS
C
1960  WRITE(5,1962) S11,S11A,S12,S12A
      WRITE(7,1962) S11,S11A,S12,S12A
1962  FORMAT(1H ,*S11:*,F8.3,4X,*<*,F6.1,5X
     1           ,*S12:*,F8.3,4X,*<*,F6.1)
      WRITE(5,1964) S21,S21A,S22,S22A
      WRITE(7,1964) S21,S21A,S22,S22A
1964  FORMAT(1H ,*S21:*,F8.3,4X,*<*,F6.1,5X
     1           ,*S22:*,F8.3,4X,*<*,F6.1)
C
C  OUTPUT OPTIMUM SOURCE AND LOAD IMPEDANCE
C
      GINM = CABS(GAMS)
      GINA = ATAN2(AIMAG(GAMS),REAL(GAMS))*180./PI
      GOUTM = CABS(GAML)
      GOUTA = ATAN2(AIMAG(GAML),REAL(GAML))*180./PI
      WRITE(5,1966) GINM,GINA,GOUTM,GOUTA
```

```
      WRITE(7,1966) GINM,GINA,GOUTM,GOUTA
1966  FORMAT(1H ,*OPTIMUM SOURCE*,F7.2,2X,*<*,F6.1,6X,
     1       *OPTIMUM LOAD*,F7.3,2X,*<*,F6.1)
      IF (STABLE.GT.1.) GO TO 1976
      GAIN = 0.
      WRITE(5,1972) STABLE
      WRITE(7,1972) STABLE
1972  FORMAT(* K=*,F6.3,*   DEVICE NOT INHERENTLY STABLE*,/,1H )
      RETURN
C
C  CALCULATE THE MAXIMUM POWER GAIN
C
1976  GAIN = 10.*ALOG10(S21/S12*(STABLE-SQRT(STABLE*STABLE-1.)))
C
C  CALCULATE THE ASSOCIATED GAIN
C
      ZSOPT = CMPLX(RSOPT,XSOPT)
      ZO = 50.
      GAMS = (ZSOPT-ZO)/(ZSOPT+ZO)
      S22P = S(2,2)+S(1,2)*S(2,1)*GAMS/(1.-S(1,1)*GAMS)
      ASGAIN = (1.-CABS(GAMS)**2)/CABS(1.-S(1,1)*GAMS)**2*S21*S21
     1          /(1.-CABS(S22P)**2)
      IF (ASGAIN.LE.0.) GO TO 1980
      ASGAIN = 10.*ALOG10(ASGAIN)
      WRITE(5,1978) STABLE,GAIN,ASGAIN
      WRITE(7,1978) STABLE,GAIN,ASGAIN
1978  FORMAT(* K=*,F6.2,*  DEVICE INHERENTLY STABLE WITH MAX POWER*,
     1       * GAIN OF*,F6.2,* DB*,/,1H ,*THE ASSOCIATED GAIN IS*,
     2       F6.2,* DB*,/,1H )
      RETURN
1980  DISPLAY*ASSOCIATED GAIN CALCULATED IS NEGATIVE.  WILL RETURN.*
      RETURN
      END
```

```
*ANCIL2
      SUBROUTINE ANCIL2 (IDP)
C  THIS SUBROUTINE EVALUATES THE PARASITIC RESISTANCES USING THE
C  EQUATIONS OF THE FUKUI MODEL
C
      COMMON/CONSTS/ECHARG,AMU0,VSAT,DIELC,BOLTZK,DIFCON,PI
      COMMON/EXTRAP/GL,Z,A,DOPEC,T,VGG,VDD,RPF,RPDR,RPM,ATITLE(7),PHI,F,
     1         TPROFIL,DOPEIN(101),DOP(101),DOPB(101),DOP2B(101)
      COMMON/PAROUT/FMIN,GM,CSG,CGD,CSD,RPI,GL1,GL2,RD,RSOPT,YSOPT
      COMMON/ANCPAR/SSG,SL,DOPES,DOPEG,RSCS,RSHS,RSHG,SGD,DL,
     1              DOPED,DOPEGD,RSCD,RSHD,IREG,ISYM
C
      RHO = 3.
      H = GL*1.E4/3.
2010  RC = 2.
      SSG = 1.E-4
      A1 = .3E-4
      A2 = A1
2020  TZ = Z*10.
      TGL = GL*1.E4
      TF = F*1.E-9
      TSSG = SSG*1.E4
      TDOP = DOPEC*1.E-16
      TA1 = A1*1.E4
      TA2 = A2*1.E4
C
C  GATE RESISTANCE.  FEED  COMPENSATES FOR DIFFERENT FEED CONFIGURATIONS
C
2030  FEED = 16.
      RGM = 3.3*RHO*TZ/H/TGL/FEED
      RGSE = .6*TZ*SQRT(RHO*TF/H/TGL)
      RPM = RGM+RGSE
      RSCHA = 1.E*TSSG/TDOP/TA1/TZ
      RSCON = SQRT(.15*RC/TDOP/TA2)/TZ
      RPF = RSCHA+RSCON
2040  RPDR = RPF
      RETURN
      END
```

```
100 REM PROGRAM CALCULATES FET CHARACTERISTICS USING PUCEL MODEL AS
110 REM MODIFIED BY J. M. ANDRES   TO INCORPORATE ARBITRARY VERTICAL DOPING PROFILE.
120 REM PROFILE ENTERED AT N1 POINTS AND SEVERAL FUNCTIONS ARE COMPUTED AND
130 REM STORED AT EACH POINT.SOLUTION INVOLVES INTERPOLATION BETWEEN
140 REM STORED POINTS TO DETERMINE S,P,ID AND OTHER QUANTITIES.
150 REM USER SUPPLIES U1,MOBILITY,E1,SATURATION FIELD,A,CHANNEL DEPTH,
160 REM Z,GATE WIDTH,L,GATE LENGTH,R1 AND R3 GATE-SOURCE AND GATE-DRAIN
170 REM RESISTANCES,DS,THE DELTA IN ELECTRON TEMPERATURE,D,THE DIFFUSION CONSTANT DIVIDED DS,AND R4, THE GATE
 RESISTANCE.
180 READ U1,E1,A,Z,L,R1,R3,DS,D,R4
190 W1=1.6E-19*A↑2/8.854E-14/12.5
200 G1=1.6E-19*Z*U1*E1*A
210 AS=PI*L/2/A
220 PRINT ≡INPUT NUMBER OF SEGMENTS≡
230 INPUT N1
240 DIM N(0:N1)+     N(I) IS DOPING DENSITY FUNCTION
250 DIM A(0:N1)+     A(I) IS INTEGRAL OF N(I)
260 DIM B(0:N1)+     B(I) IS INTEGRAL OF N(I) TIMES I
270 DIM C(0:N1)+     C(I) IS INTEGRAL OF N(I)TIMES A(I) TIMES I
300 A(0)=0,B(0)=0,C(0)=0,H=1/N1
310 N(0)=1.76862P3E16  +      GAUSSIAN PROFILE HERE . CAN PUT IN ANY N(I)
320 FOR I=1 TO N1
330 N(I)=N(0)*10*EXP(-(I-N1)↑2/N1↑2/.43429)
333 NEXT I
335 FOR I=1 TO N1-1
340 A(I)=A(I-1)+H*(2/3*N(I)-1/12*N(I+1)+5/12*N(I-1))
341 NEXT I
342 A(N1)=A(N1-1)+H*(5/12*N(N1)+2/3*N(N1-1)-1/12*N(N1-2))
345 FOR I=1 TO N1-1
350 B(I)=B(I-1)+H↑2*(2/3*I*N(I)-1/12*(I+1)*N(I+1)+5/12*(I-1)*N(I-1))
360 C(I)=C(I-1)+H↑2*(2/3*I*N(I)*A(I)-1/12*(I+1)*N(I+1)*A(I+1)+5/12*(I-1)*N(I-1)*A(I-1))
361 NEXT I
362 B(N1)=B(N1-1)+H↑2*(5/12*N1*N(N1)+2/3*(N1-1)*N(N1-1)-1/12*(N1-2)*N(N1-2))
363 C(N1)=C(N1-1)+H↑2*(5/12*N1*N(N1)*A(N1)+2/3*(N1-1)*N(N1-1)*A(N1-1)-1/12*(N1-2)*N(N1-2)*A(N1-2))
390 PRINT ≡VPINCH=≡;W1*B(N1)
400 PRINT ≡INPUT VGG (USUALLY NEGATIVE)≡
410 INPUT V1
420 R2=R3-4*V1 +  EMPIRICAL INCREASE OF DRAIN RESISTANCE WITH VGG
430 V1=-V1+.9 +  INCLUSION OF BUILT-IN POTENTIAL (CHOSEN TO FIT)
440 S0=0,P0=0
450 DEF FNS(I,J)=V1-W1*B(I)+R1*G1*(A(N1)-A(J))
460 DEF FNY(I,J)=1-(A(N1)*(B(J)-B(I))-C(J)+C(I))/E1/L*W1/(A(N1)-A(J))
```

```
470 FOR I=0 TO N1
480 IF FNS(I,T)>0 THEN 510
490 S1=I-1
500 GO TO 520
510 NEXT I
520 FOR J=0 TO N1
530 IF FNY(S1,J)>0 THEN 560
540 P1=J-1
550 GO TO 570
560 NEXT J
570 D1=(FNS(S1+1,P1)-FNS(S1-1,P1))/2
580 D2=(FNY(S1+1,P1)-FNY(S1-1,P1))/2
590 F1=(FNS(S1,P1+1)-FNS(S1,P1-1))/2
600 F2=(FNY(S1,P1+1)-FNY(S1,P1-1))/2
610 H1=-FNS(S1,P1)
620 H2=-FNY(S1,P1)
630 S2=(H1*F2-H2*F1)/(D1*F2-D2*F1)
640 P2=(D1*H2-D2*H1)/(D1*F2-D2*F1)
650 S=(S1+S2)/N1,P=(P1+P2)/N1
660 IF S=S0 AND P=P0 THEN 700
670 S0=S,P0=P
671 IF S2<0 THEN S1=S1+INT(S2-.5)
672 IF P2<0 THEN P1=P1+INT(P2-.5)
673 IF S2>0 THEN S1=S1+INT(S2+.5)
674 IF P2>0 THEN P1=P1+INT(P2+.5)
690 GO TO 570
700 PRINT "S=";S,"P=";P
710 A1=A(S1)+S2*(A(S1+1)-A(S1-1))/2+S2↑2/2*(A(S1+1)-2*A(S1)+A(S1-1))
720 A2=A(P1)+P2*(A(P1+1)-A(P1-1))/2+P2↑2/2*(A(P1+1)-2*A(P1)+A(P1-1))
730 B1=B(S1)+S2*(B(S1+1)-B(S1-1))/2+S2↑2/2*(B(S1+1)-2*B(S1)+B(S1-1))
740 B2=B(P1)+P2*(B(P1+1)-B(P1-1))/2+P2↑2/2*(B(P1+1)-2*B(P1)+B(P1-1))
750 PRINT "ID=";G1*(A(N1)-A2)
760 V2=W1*(B2-B1)
770 V3=V2+G1*(R1+R2)*(A(N1)-A2)
780 PRINT "VSD=";V2,"VDD=";V3+      THIS VDD IS THAT JUST SATURATING AT END OF FET
790 PRINT "TYPE VDD"
800 INPUT V4
810 IF V4<0 THEN GO TO 400
820 IF V4<V3 THEN GO TO 2040
830 P1=S1
840 DEF FNW(I,J)=W1*(B(J)-B(I))+E1*L/A$/2*(EXP(A$*FNY(I,J))-EXP(-A$*FNY(I,J)))
850 DEF FNV(I,J)=V4-FNW(I,J)-G1*(R1+R2)*(A(N1)-A(J))
```

```
860 D4=(FNS(S1+1,P1)-FNS(S1-1,P1))/2
870 F4=(FNS(S1,P1+1)-FNS(S1,P1-1))/2
880 H4=-FNS(S1,P1)
890 D3=(FNV(S1+1,P1)-FNV(S1-1,P1))/2
900 F3=(FNV(S1,P1+1)-FNV(S1,P1-1))/2
910 H3=-FNV(S1,P1)
920 S2=(H4*F3-H3*F4)/(D4*F3-D3*F4)
930 P2=(D4*H3-D3*H4)/(D4*F3-D3*F4)
940 S=(S1+S2)/N1,P=(P1+P2)/N1
950 IF S=S0 AND P=P0 THEN 990
960 S0=S,PC=P
962 IF S2<0 THEN S1=S1+INT(S2-.5)
964 IF P2<0 THEN P1=P1+INT(P2-.5)
966 IF S2>0 THEN S1=S1+INT(S2+.5)
970 IF P2>0 THEN P1=P1+INT(P2+.5)
980 GO TO 860
990 A1=A(S1)+S2*(A(S1+1)-A(S1-1))/2+S2↑2*(A(S1+1)-2*A(S1)+A(S1-1))/2
1000 A2=A(P1)+P2*(A(P1+1)-A(P1-1))/2+P2↑2*(A(P1+1)-2*A(P1)+A(P1-1))/2
1010 B1=B(S1)+S2*(B(S1+1)-B(S1-1))/2+S2↑2*(B(S1+1)-2*B(S1)+B(S1-1))/2
1020 B2=B(P1)+P2*(B(P1+1)-B(P1-1))/2+P2↑2*(B(P1+1)-2*B(P1)+B(P1-1))/2
1030 C1=C(S1)+S2*(C(S1+1)-C(S1-1))/2+S2↑2*(C(S1+1)-2*C(S1)+C(S1-1))/2
1040 C2=C(P1)+P2*(C(P1+1)-C(P1-1))/2+P2↑2*(C(P1+1)-2*C(P1)+C(P1-1))/2
1041 DEF FNC(I)=H*I*N(I)*(A(I))↑2
1042 F=0
1043 FOR I=S1 TO P1-1
1044 F=F+H*(2/3*FNC(I)+5/12*FNC(I+1)-1/12*FNC(I-1))
1045 NEXT I
1046 F=F-H*S2*FNC(S1)-H/4*S2↑2*(FNC(S1+1)-FNC(S1-1))
1047 D2=F+H*P2*FNC(P1)+H/4*P2↑2*(FNC(P1+1)-FNC(P1-1))
1048 D1=0
1070 L1=(A(N1)*(P2-P1)-C2+C1)/E1/L*W1/(A(N1)-A2)
1080 L2=1-L1
1090 C$=(EXP(A$*L2)+EXP(-A$*L2))/2
1100 S$=(EXP(A$*L2)-EXP(-A$*L2))/2
1110 G$=G1/W1*((A(N1)-A1)*C$-A(N1)+A2)/(F*(A(N1)-A2)*(C$-1)+E1*L*L1/W1*C$)
1120 R$=W1/G1*(P*(A(N1)-A2)*(C$-1)+E1*L*L1/W1*C$)/(A(N1)-A2)
1130 PRINT "S=":S,"P=":P,"ID=":G1*(A(N1)-A2)
1135 PRINT "EQUIVALENT CIRCUIT PARAMETERS"
1140 PRINT "GM=":G$,"RD=":R$,"GM*=":G$/(1+G$*R1)
1150 C4=G$*W1/G1*(P*A2+(A(N1)*(C2-C1)-D2+D1)/(A(N1)-A2)↑2)
1160 C4=Z*1.6E-19*A/R1*(C4-(A(N1)-A1)*A1/(A(N1)-A2))
1170 C5=(1-P*G$*W1/G1)*(Z*1.6E-19*A*A2/E1/C$+Z*12.5*8.854E-14*S$/C$)
```

```
1180 C5=C5+Z*1.6E-19*A*L2*L*G$/G1
1190 C6=C4+C5+Z*12.5*8.85E-14*1.56
1191 T=(A(N1))↑2*(B2-B1)-2*A(N1)*(C2-C1)+D2-D1
1192 T=L/L1/F1*(T*W1/F1/L/(A(N1)-A2)↑2+L2)+ T IS TRANSIT TIME
1193 R5=T/C6/4+ R5 IS GATE CHARGING RESISTANCE (FACTOR OF 4 GIVES FIT)
1194 PRINT "T=";T,"RI=";R5
1200 PRINT "CSG=";C6
1210 G2=W1/E1/L1/L*P*(A(N1)-A2)*(1-1/C$)+1+ G2 IS GAMMA
1220 DEF FNF(I)=N(I)*(A(N1)*B(I)-C(I))
1230 F=0
1240 FOR I=S1 TO P1-1
1250 F=F+H*(2/3*FNF(I)+5/12*FNF(I+1)-1/12*FNF(I-1))
1260 NEXT I
1270 F=F-H*S2*FNF(S1)-H/4*S2↑2*(FNF(S1+1)-FNF(S1-1))
1275 F=F+H*P2*FNF(P1)+H/4*P2↑2*(FNF(P1+1)-FNF(P1-1))
1280 F=F-(A(N1)*B1-C1)*(A2-A1)
1290 K$=F*W1/F1/L1/L/(A(N1)-A2)-G2*A2-L2/L1*(A(N1)-A2)+ K$ IS -K#
1300 K1=K$+G2*A2
1320 DEF FNP(I)=H*I*N(I)*(A(N1)-A(I))↑2
1330 F=0
1340 FOR I=S1 TO P1-1
1350 F=F+H*(2/3*FNP(I)+5/12*FNP(I+1)-1/12*FNP(I-1))
1360 NEXT I
1370 F=F-H*S2*FNP(S1)-H/4*S2↑2*(FNP(S1+1)-FNP(S1-1))
1375 P4=F+H*P2*FNP(P1)+H/4*P2↑2*(FNP(P1+1)-FNP(P1-1))+  P4 IS PO
1380 DEF FNQ(I)=H*I*N(I)/(A(N1)-A(I))
1390 F=0
1400 FOR I=S1 TO P1-1
1410 F=F+H*(2/3*FNQ(I)+5/12*FNQ(I+1)-1/12*FNQ(I-1))
1420 NEXT I
1430 F=F-H*S2*FNQ(S1)-H/4*S2↑2*(FNQ(S1+1)-FNQ(S1-1))
1435 F=F+H*P2*FNQ(P1)+H/4*P2↑2*(FNQ(P1+1)-FNQ(P1-1))
1440 P$=F*D$*(A(N1)-A2)↑3+  P$ IS P DELTA
1460 DEF FNR(I)=H*(I*N(I)*(K$+G2*A(I))↑2*(A(N1)-A(I))↑2)
1470 F=0
1480 FOR I=S1 TO P1-1
1490 F=F+H*(2/3*FNR(I)+5/12*FNR(I+1)-1/12*FNR(I-1))
1500 NEXT I
1510 F=F-H*S2*FNR(S1)-H/4*S2↑2*(FNR(S1+1)-FNR(S1-1))
1515 T0=F+H*P2*FNR(P1)+H/4*P2↑2*(FNR(P1+1)-FNR(P1-1))+  T0 IS R0
1520 DEF FNT(I)=H*(I*N(I)*(K$+G2*A(I))↑2/(A(N1)-A(I)))
1530 F=0
```

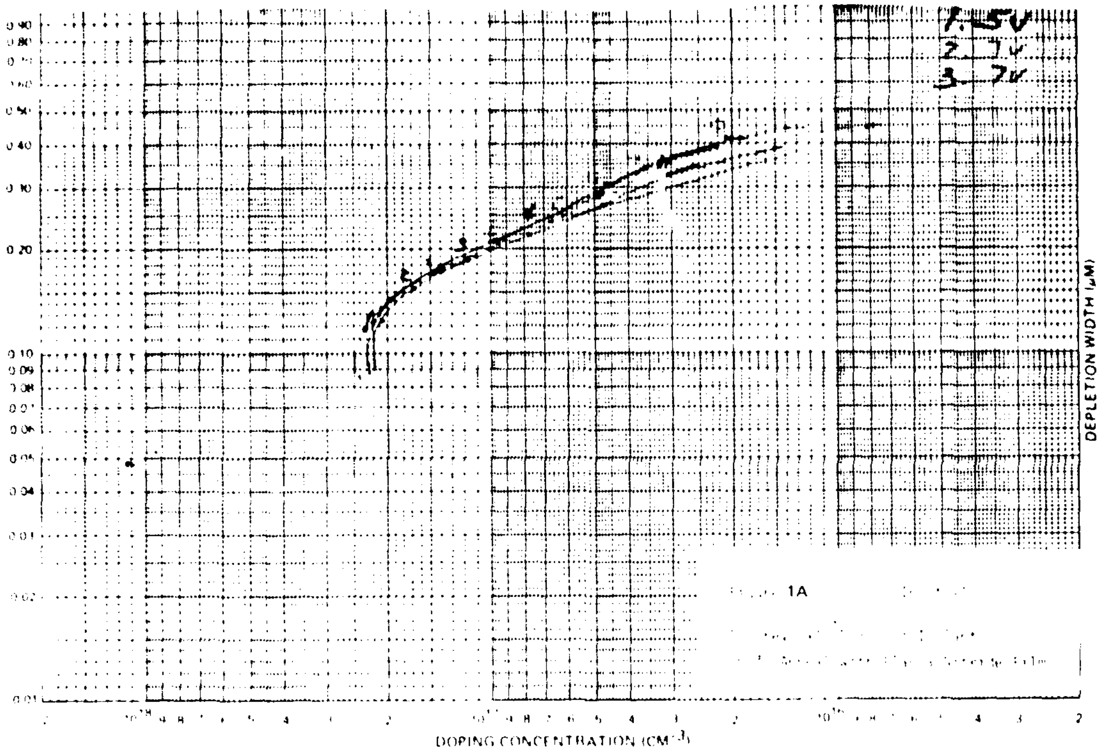
```
1540 FOR I=S1 TO P1-1
1550 F=F+H*(2/3*FNT(I)+5/12*FNT(I+1)-1/12*FNT(I-1))
1560 NEXT I
1570 F=F-H*S2*FNT(S1)-H/4*S2↑2*(FNT(S1+1)-FNT(S1-1))
1575 F=F+H*P2*FNT(P1)+H/4*P2↑2*(FNT(P1+1)-FNT(P1-1))
1580 T$=F*D$*(A(N1)-A2)↑3 ↓     T$ IS R DELTA
1600 DEF FNU(T)=H*(T*N(T)*(K$+G2*A(I))*(A(N1)-A(I))↑2)
1610 F=0
1620 FOR I=S1 TO P1-1
1630 F=F+H*(2/3*FNU(T)+5/12*FNU(I+1)-1/12*FNU(I-1))
1640 NEXT I
1650 F=F-H*S2*FNU(S1)-H/4*S2↑2*(FNU(S1+1)-FNU(S1-1))
1655 F=F+H*P2*FNU(P1)+H/4*P2↑2*(FNU(F1+1)-FNU(P1-1))
1660 S4=-F ↓                        S4 IS S0
1670 DEF FNX(T)=H*(I*N(T)*(K$+G2*A(I))/(A(N1)-A(I)))
1680 F=0
1690 FOR I=S1 TO P1-1
1700 F=F+H*(2/3*FNX(T)+5/12*FNX(I+1)-1/12*FNX(I-1))
1710 NEXT I
1720 F=F-H*S2*FNX(S1)-H/4*S2↑2*(FNX(S1+1)-FNX(S1-1))
1725 F=F+H*P2*FNX(F1)+H/4*F2↑2*(FNX(F1+1)-FNX(P1-1))
1730 S5=-F*D$*(A(N1)-A2)↑3↓      S5 IS S DELTA
1750 P5=W1*C$↑2/R$↑2/G$/G1/(A(N1)-A2)↑3*(P4+P$)↓  P5 IS P1
1770 T1=G$*C$↑2/R$↑2/C6↑2*(W1/G1)↑3*(Z*12.5*8.85E-14*L1*L/A)↑2
1780 T1=T1*(T2+T$)/(A(N1)-A2)↑5↓    T1 IS R1
1800 C7=(S4+S5)/((P4+P$)*(TC+T$))↑.5↓   C7 IS C11
1820 F7=16/PI↑3*D*(SIN(PI/2*(1-P))/(PI/2*(1-P)))↑2
1830 F7=F7*(EXP(2*A$*L2)-4*EXP(A$*L2)+3+2*A$*L2) ↓ F7 IS LITTLE F3
1840 P6=F7*G1*(A(N1)-A2)*A/4/G$/E1↑3/(U1*R$*Z*12.5*8.854E-14)↑2↓ P6 IS P2
1850 T2=P6*(Z*1.6E-19*A/G1*L1/(A(N1)-A2)*L/C6*G$*K1)↑2↓  T2 IS R2
1870 P7=P5+P6↓   P7 IS P=P1+P2
1880 T3=T1+T2↓      T3 IS R=R1+R2
1890 C8=C7*(P5*T1/P7/T3)↑.5+(P6*T2/P7/T3)↑.5↓  C8 IS C ,CORRELATION
1900 K2=P7-2*C8*(P7*T3)↑.5+T3 ↓       K2 IS K SUB G
1910 K3=(P7-C8*(P7*T3)↑.5)/K2 ↓     K3 IS K SUB C
1920 K4=P7*T3*(1-C8↑2)/K2 ↓     K4 IS K SUB R
1925 PRINT≡NOISE PARAMETERS VS FREQ FOR BIAS VOLTAGES SELECTED≡
1930 PRINT ≡TYPE FREQ GHZ≡
1940 INPUT F
1945 IF F<0 THEN 700
1950 F=F*1E9
1960 G3=(2*PI*F*C6)↑2*K2/G$ ↓     G3 IS LITTLE G SUB N
```

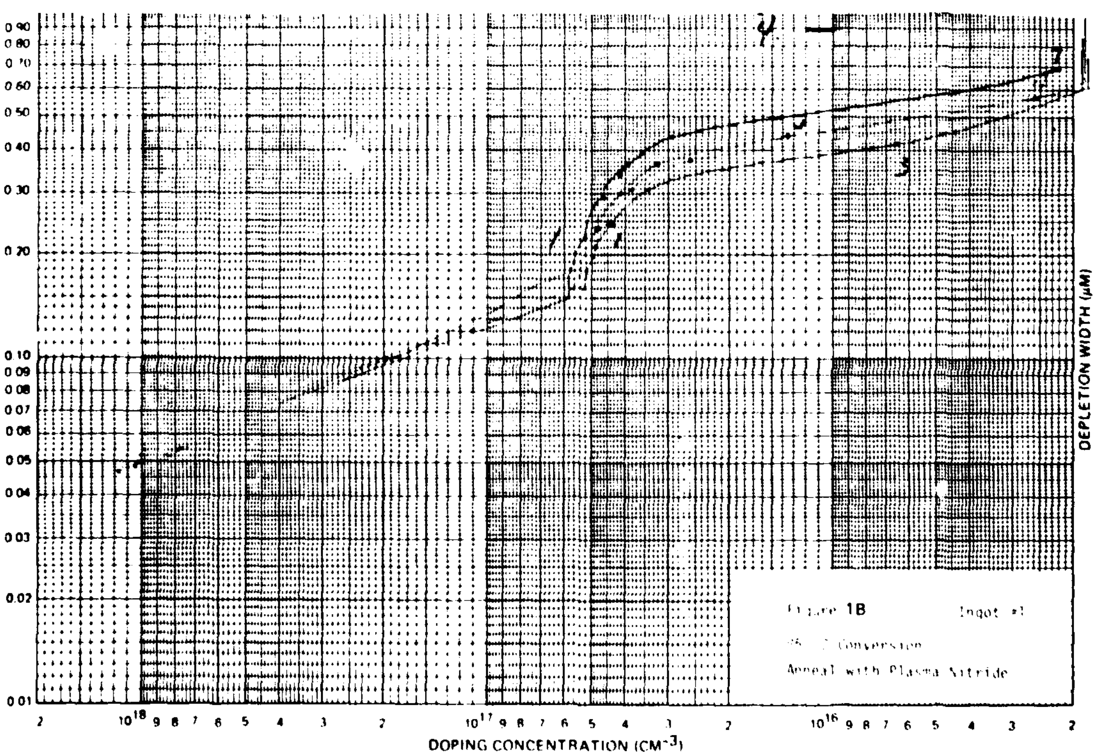
```
1970 R6=R1+R4+(1+(2*PI*F*C6*R5)↑2)*K4/G$↓  R6 IS LITTLE R SUB N
1980 R7=R1+R4+K3*R5 ↓     R7 IS R SUB C
1990 X7=-K3/(2*PI*F*C6)↓     X7 IS X SUB C
2000 PRINT "CN=";C3,"RN=";R6,"R0=";(R7↑2+R6/G3)↑.5,"X0=";-X7
2010 F$=1+2*G3*(R7+(R7↑2+R6/G3)↑.5)
2020 PRINT "FOPT=";F$,"FOPT(DB)=";10*LOG10(F$)
2030 GO TO 1930
2040 DEF FNG(I,J)=W1*B(J)+R2/R1*W1*B(I)-V4-V1/R1*(R1+R2)
2050 DEF FND(I,J)=P1*W1*G1/E1/L*(A(N1)*(B(J)-B(I))-C(J)+C(I))+V1-W1*B(I)
2060 D5=FND(S1+1,P1)-FND(S1,P1)
2070 D6=FNG(S1+1,P1)-FNG(S1,P1)
2080 F5=FND(S1,P1+1)-FND(S1,P1)
2090 F6=FNG(S1,P1+1)-FNG(S1,P1)
2100 H5=-FND(S1,P1)
2110 H6=-FNG(S1,P1)
2120 S2=(H5*F6-H6*F5)/(D5*F6-D6*F5)
2130 P2=(D5*H6-D6*H5)/(D5*F6-D6*F5)
2140 S=(S1+S2)/N1,P=(P1+P2)/N1
2150 IF S=SO AND P=PO THEN 2190
2160 SO=S,PO=P
2170 S1=S1+INT(S2),P1=P1+INT(P2)
2180 GO TO 2060
2190 B1=B(S1)+S2*(B(S1+1)-B(S1))
2200 B2=B(P1)+P2*(B(P1+1)-B(P1))
2210 C1=C(S1)+S2*(C(S1+1)-C(S1))
2220 C2=C(P1)+P2*(C(P1+1)-C(P1))
2230 PRINT "ID=";W1*G1/E1/L*(A(N1)*(B2-B1)-C2+C1)
2240 GO TO 790
2250 DATA 4500,2900,2.0E-5,265E-4,2E-4,15,25,1.2,.318,.8
2260 END
```

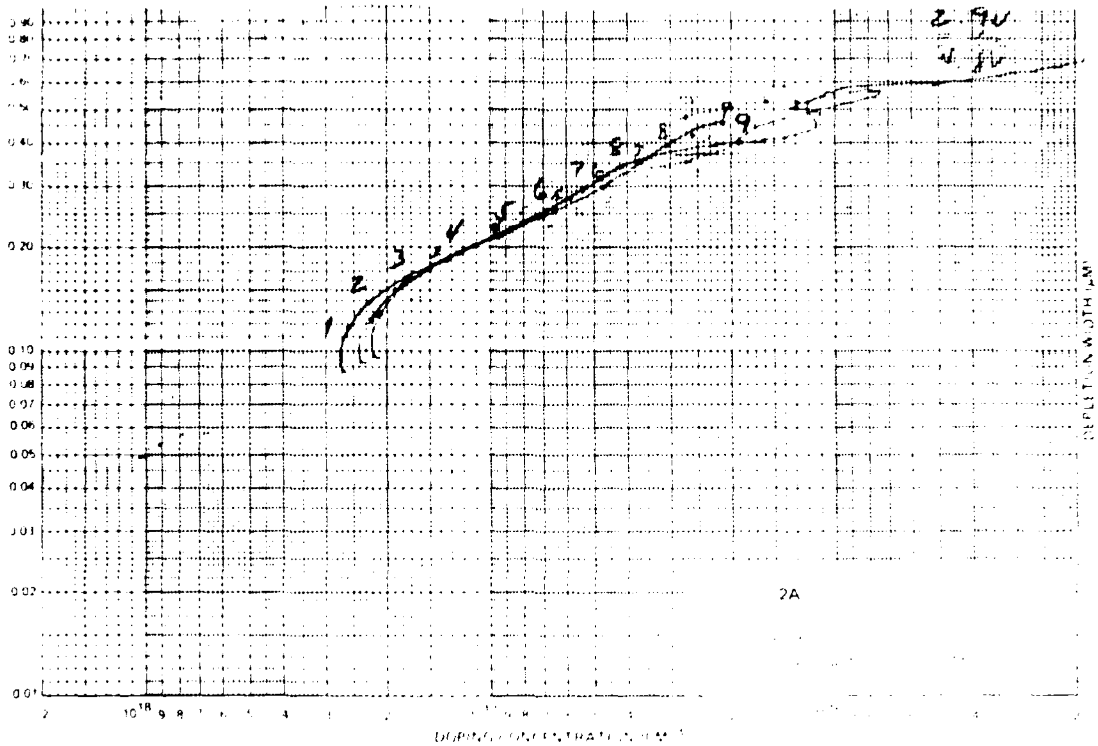
APPENDIX C
SUPPLEMENTARY PROCESSING DATA

Several GaAs samples from different vendors were evaluated for thermal conversion and implant damage enhanced conversion. Data shown in Figures 1 through 5 is typical of ingots which did not pass the qualification tests. The A figures show thermal conversion without implant. The B figures show ion implant profiles characteristic of these wafers which convert.

The implant data of a series of qualified wafers which have been implanted for device and circuit application are presented in Figures 6 through 36 in two groups: 100 keV implants for a pinchoff of 1 to 2 volts are shown in Figures 6 through 28 and 200 keV implants for a 3 to 4 volt pinchoff are shown in Figures 29 through 36. This data indicates a high degree of repeatability.


1.5V
2. 7V
3. 7V
DEPLETION WIDTH (μM)
DOPING CONCENTRATION (CM⁻³)
1A
Anneal with Plasma Nitride Film


DEPLETION WIDTH (μM)
DOPING CONCENTRATION (CM⁻³)
Figure 1B
Ingot #1
Conversion
Anneal with Plasma Nitride


2A
DEPLETION WIDTH (μM)
DOPING CONCENTRATION

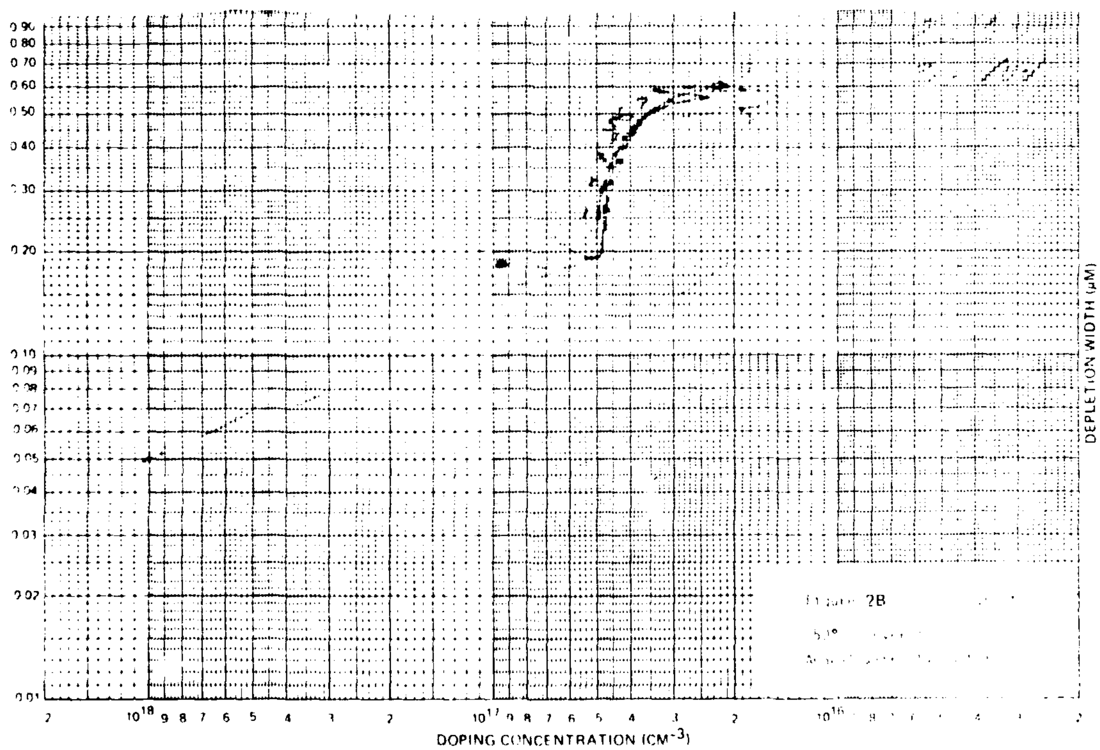
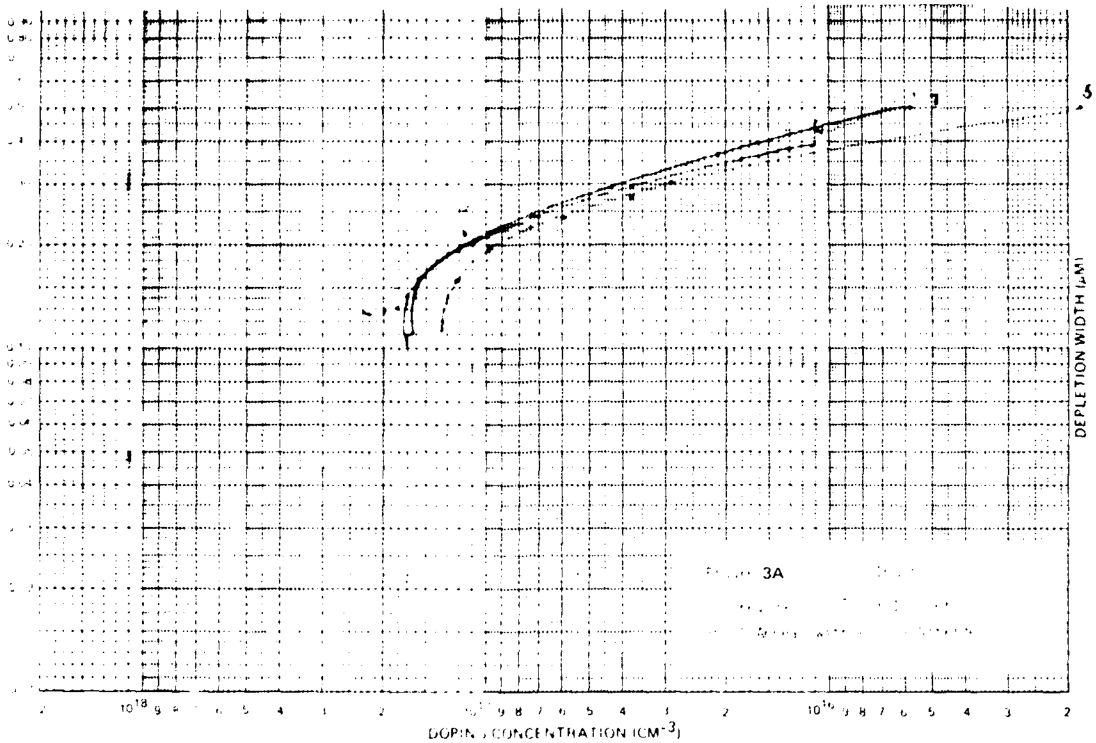


Figure 2B
DEPLETION WIDTH (μM)
DOPING CONCENTRATION (CM-3)


3A
0.2
DEPLETION WIDTH (μM)
7
5
10^{18} 9 8 7 6 5 4 3 2
10^{17} 9 8 7 6 5 4 3 2
10^{16} 9 8 7 6 5 4 3 2
DOPING CONCENTRATION (CM^{-3})

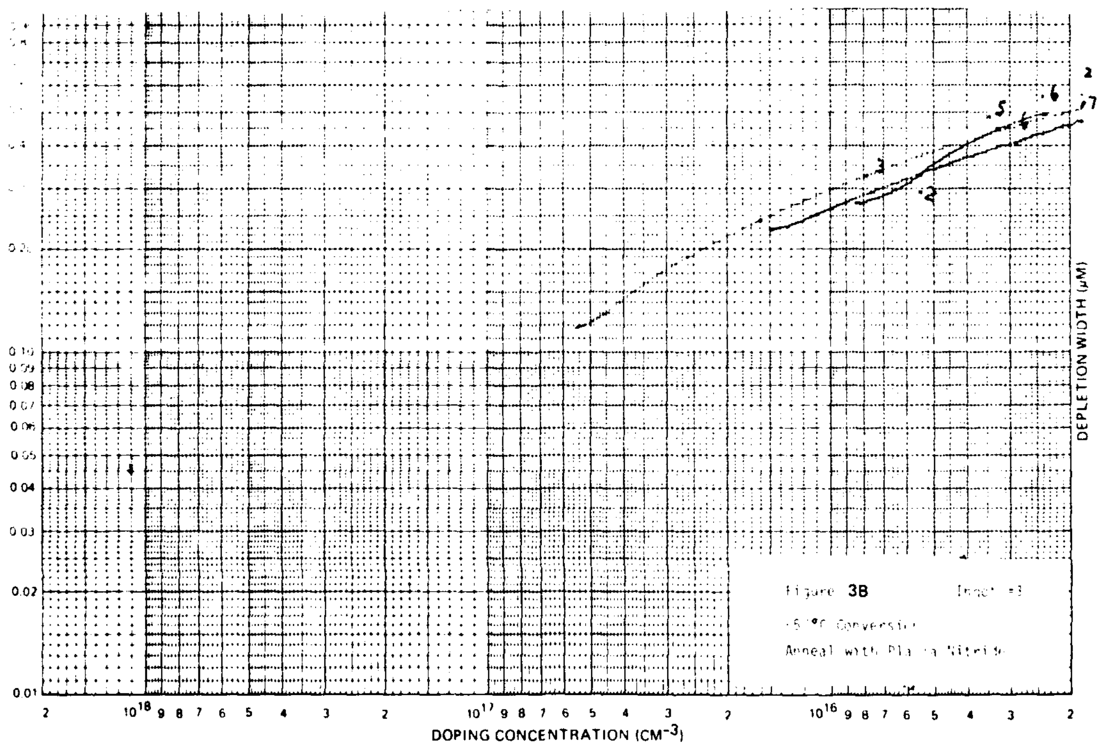


Figure 3B
Annealing with Plasma Nitride
0.4
0.2
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
DEPLETION WIDTH (μM)
2
3
5
6
7
2
10^{18} 9 8 7 6 5 4 3 2
10^{17} 9 8 7 6 5 4 3 2
10^{16} 9 8 7 6 5 4 3 2
DOPING CONCENTRATION (CM^{-3})

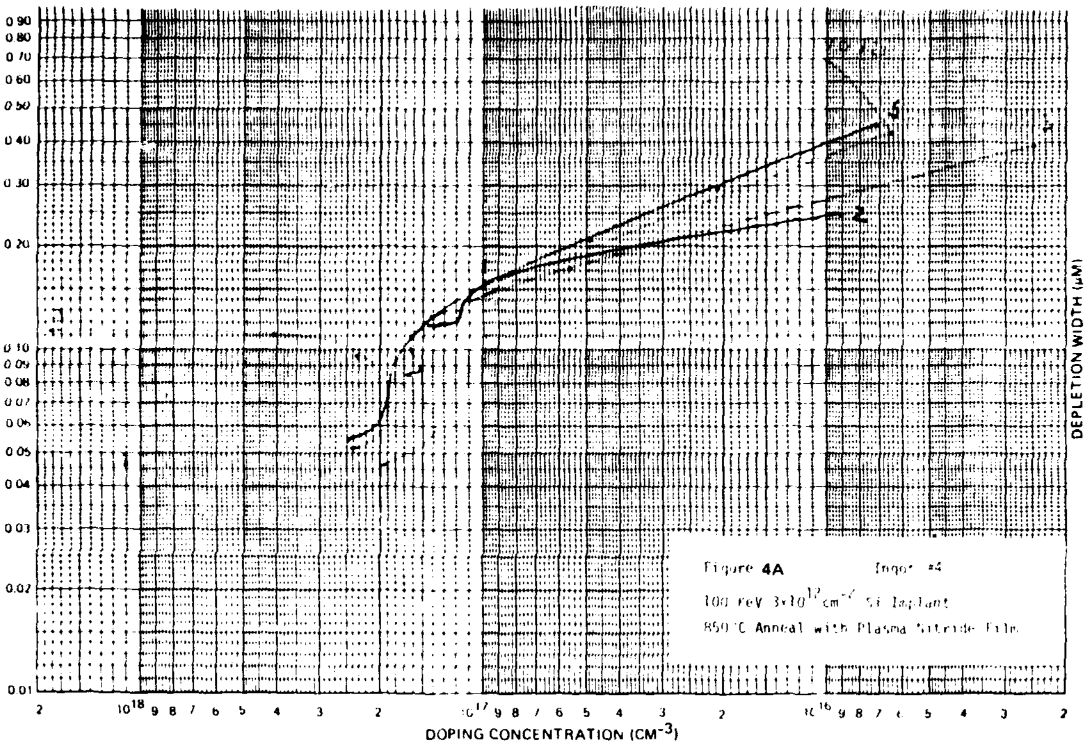


Figure **4A** Ingot #4

100 keV $3\times10^{12} cm^{-2}$ Si Implant

850°C Anneal with Plasma Nitride Film

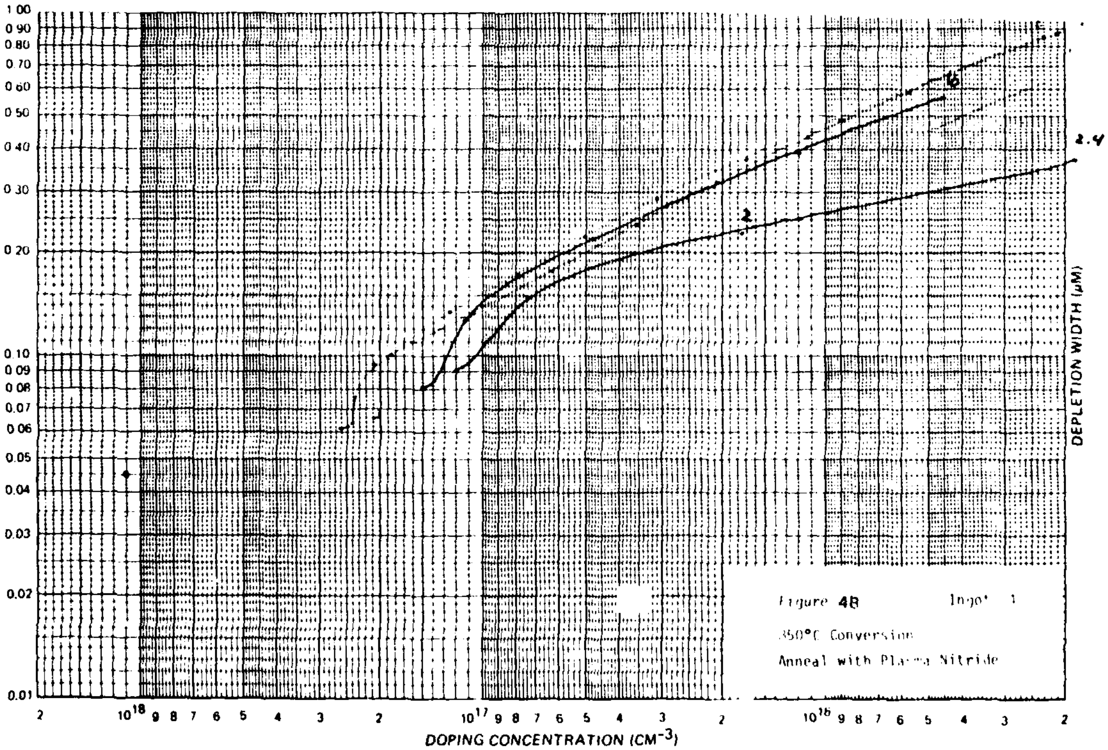


Figure **4B** Ingot 1

850°C Conversion

Anneal with Plasma Nitride

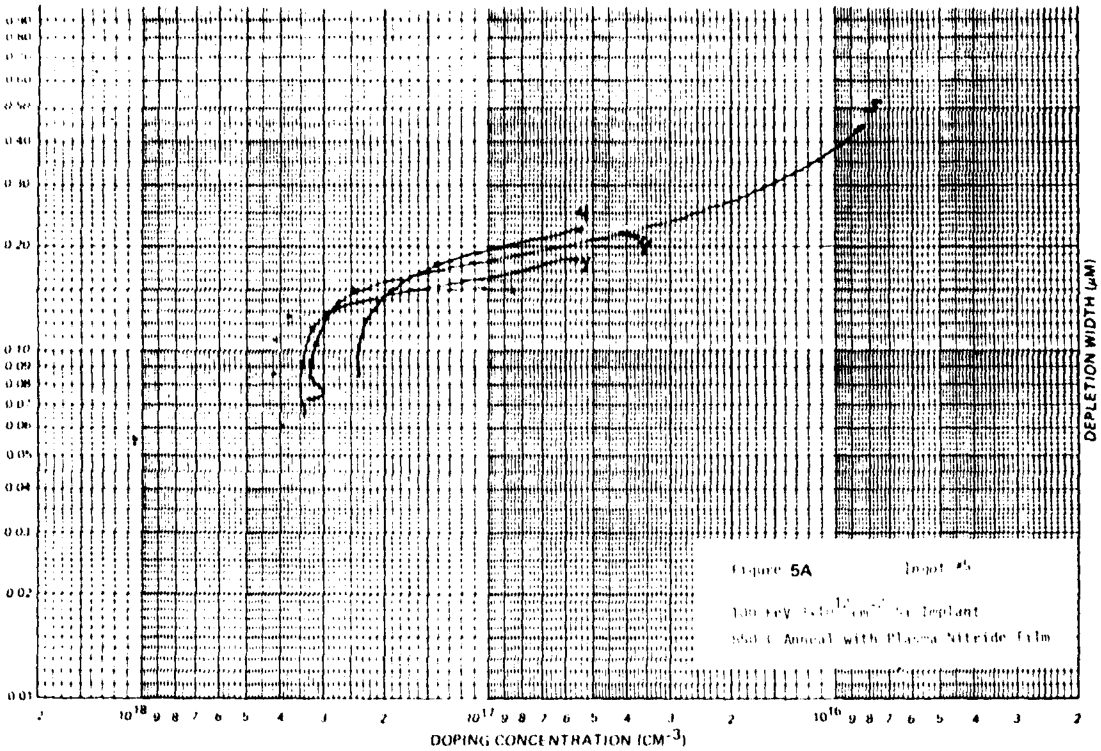


Figure 5A
Ingot #5
Implant
Anneal with Plasma Nitride Film
DEPLETION WIDTH (μM)
DOPING CONCENTRATION (CM-3)

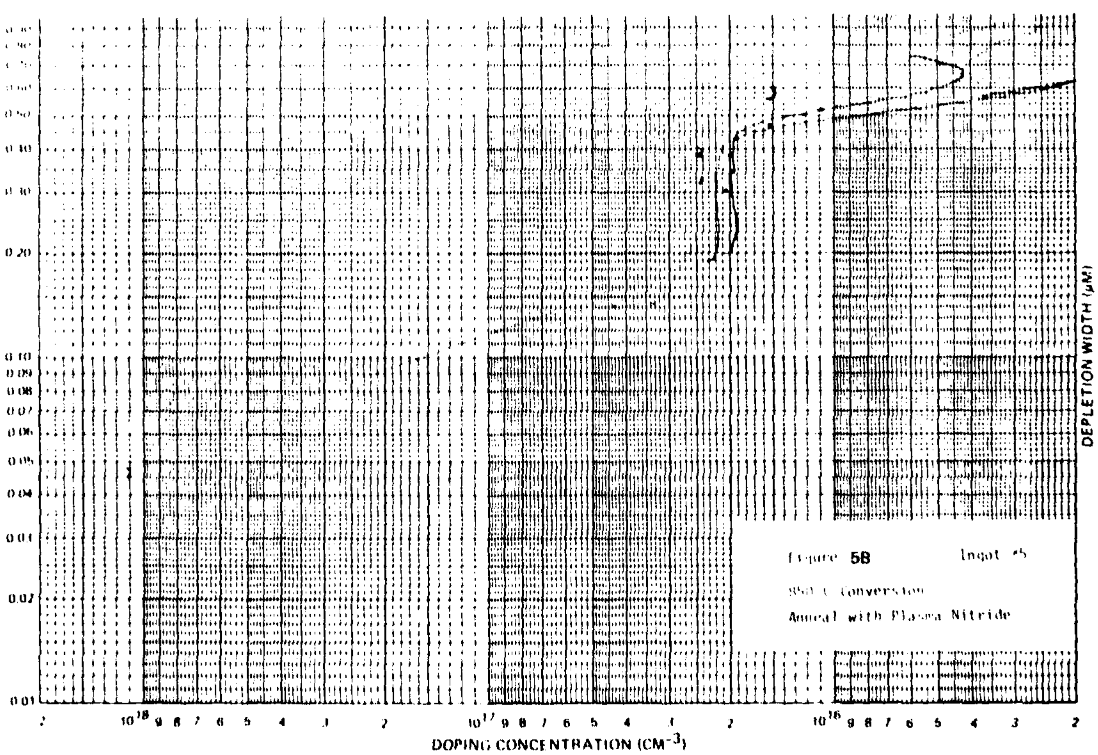


Figure 5B
Ingot #5
Conversion
Anneal with Plasma Nitride
DEPLETION WIDTH (μM)
DOPING CONCENTRATION (CM-3)

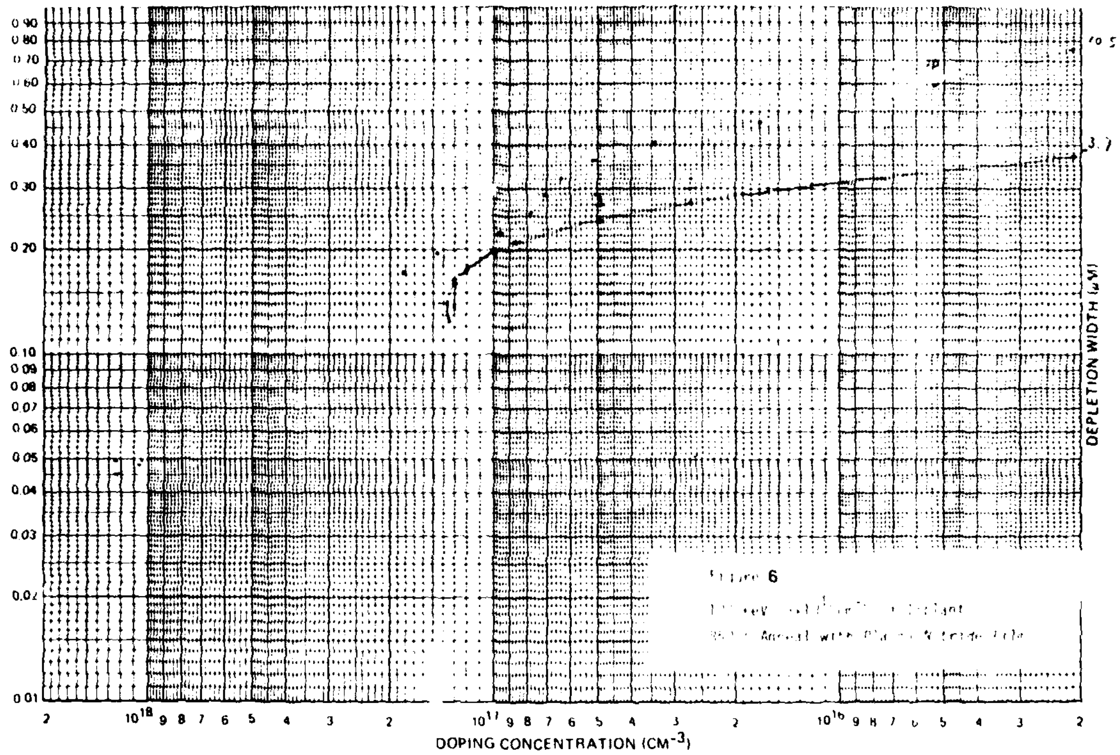

DEPLETION WIDTH (μM)
DOPING CONCENTRATION (CM-3)
keV
Anneal with

Figure 6

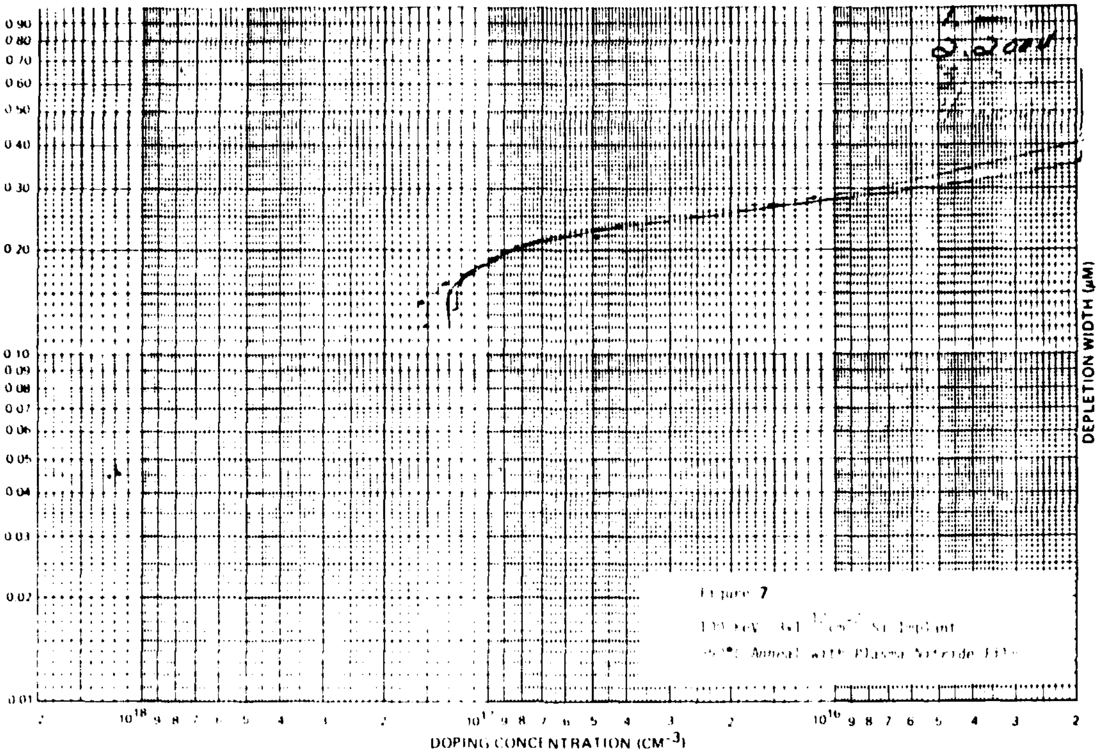


Figure 7

[illegible] keV 3x1[illegible] cm^{-2} Si Implant

[illegible]°C Anneal with Plasma Nitride File

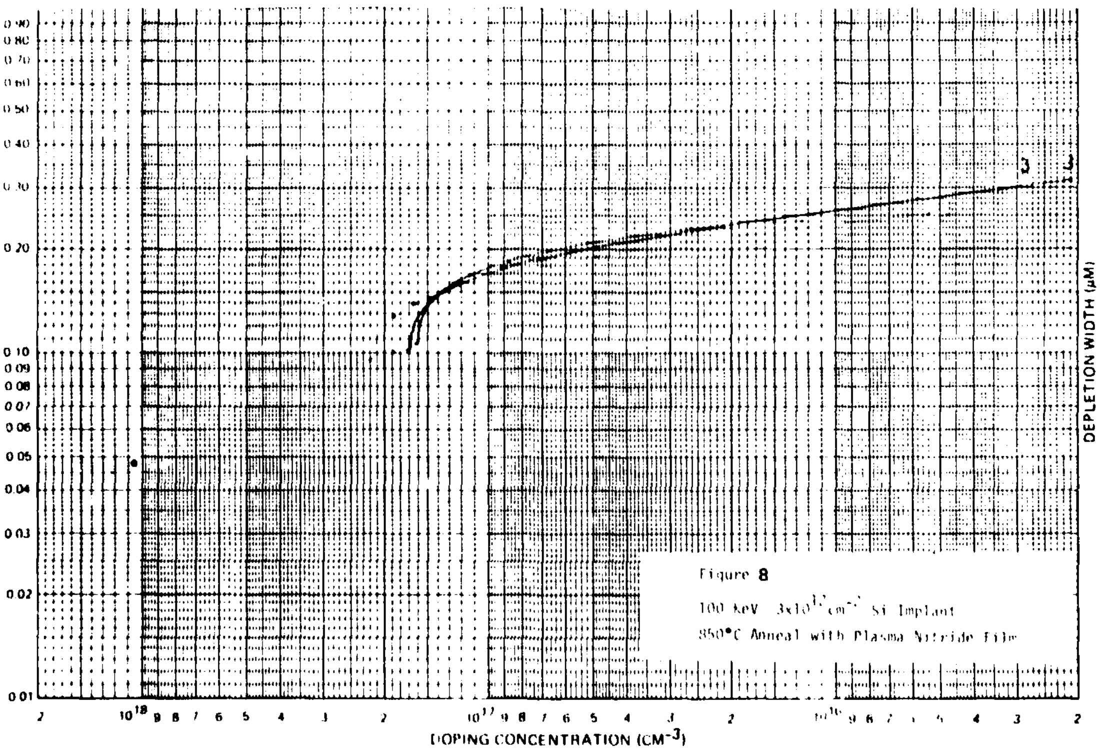


Figure 8

100 keV $3x10^{12}$ cm^{-2} Si Implant

850°C Anneal with Plasma Nitride File

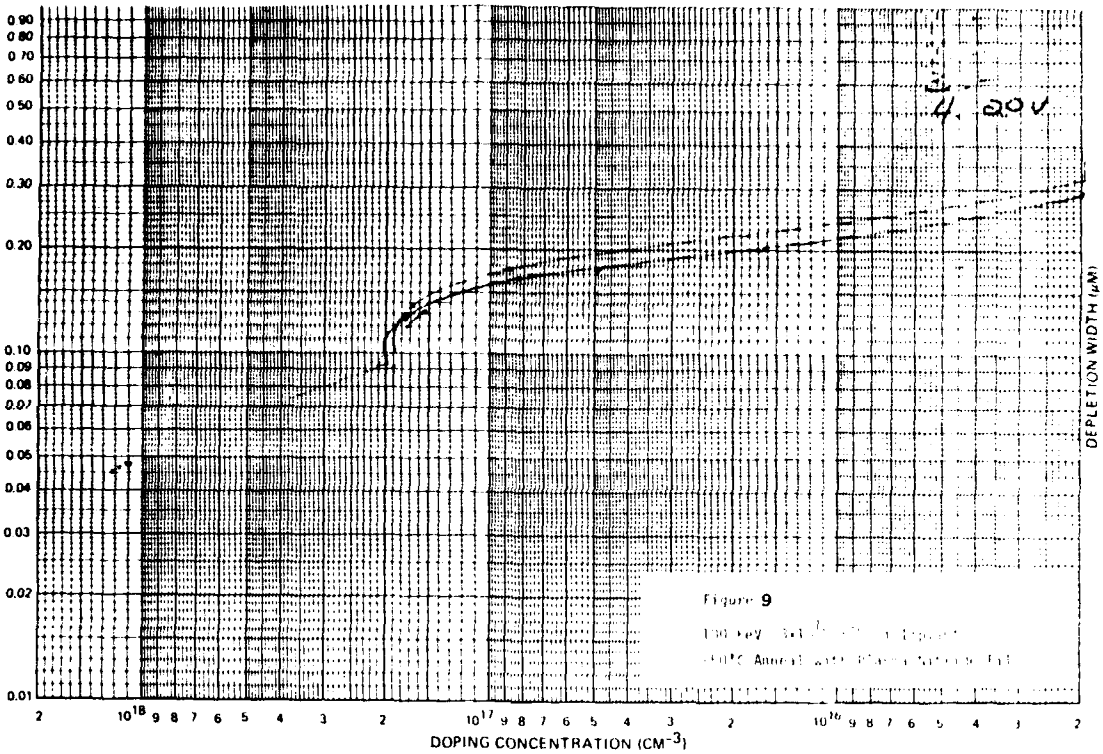


Figure 9

[illegible] KeV [illegible] Implant

[illegible] Anneal [illegible]

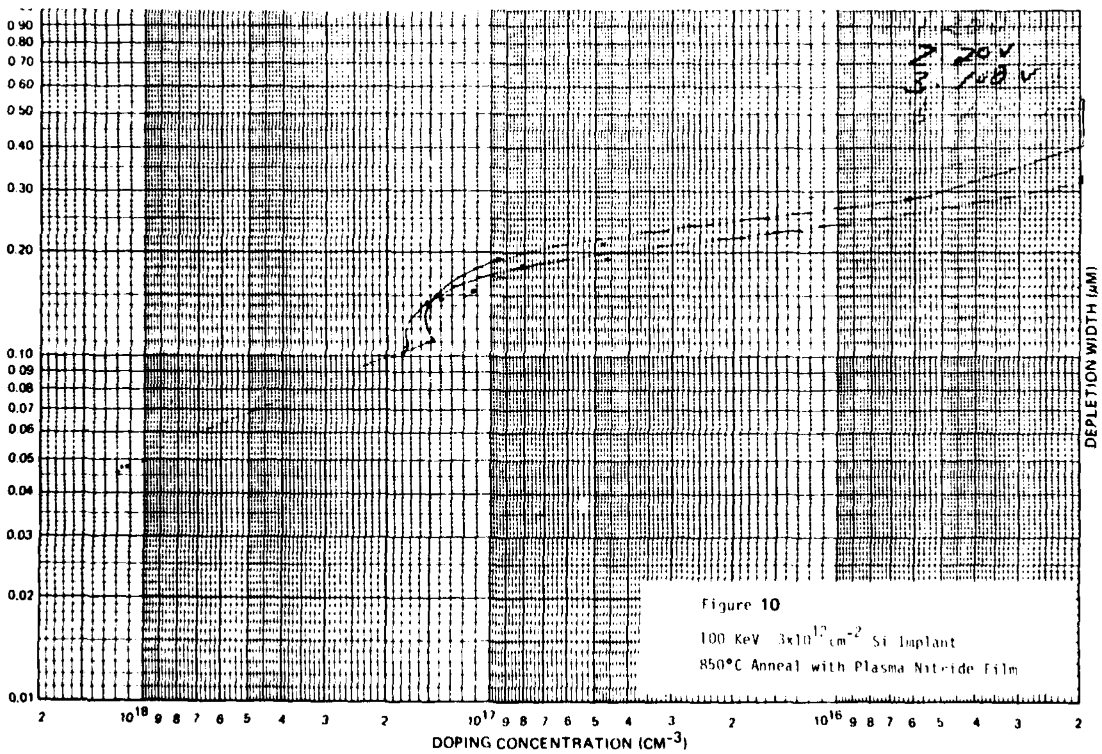


Figure 10

100 KeV 3×10^{12} cm^{-2} Si Implant

850°C Anneal with Plasma Nitride Film

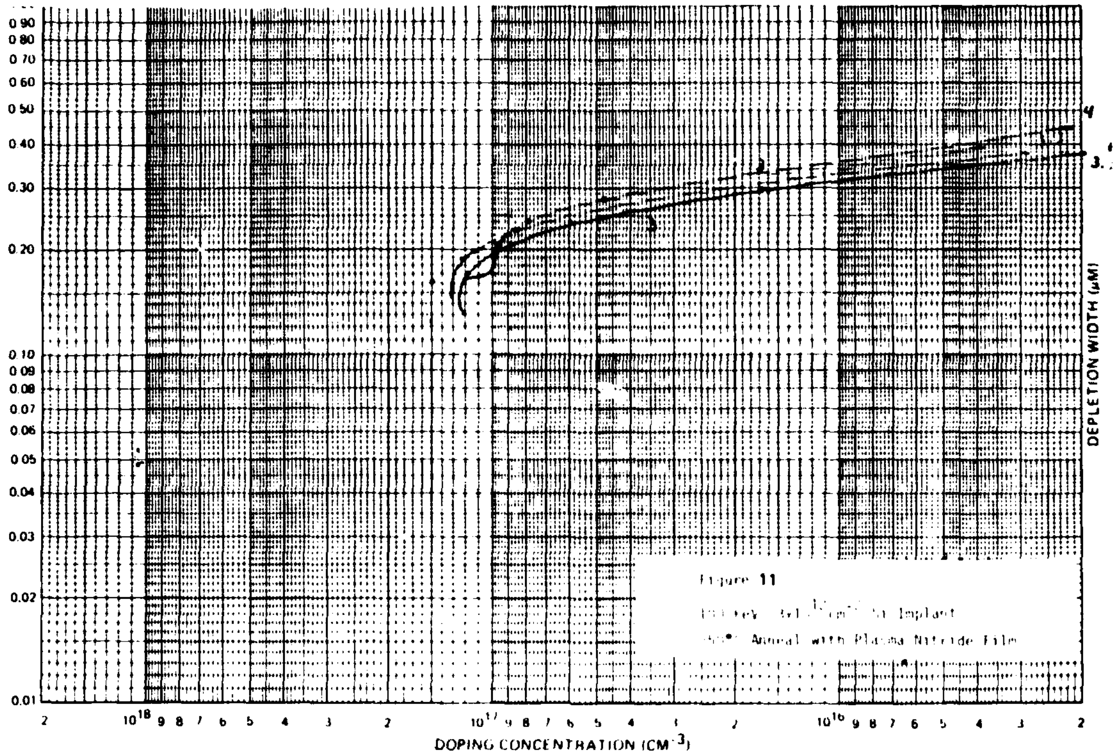


Figure 11

[illegible] KeV [illegible] Si Implant

[illegible] Anneal with Plasma Nitride Film

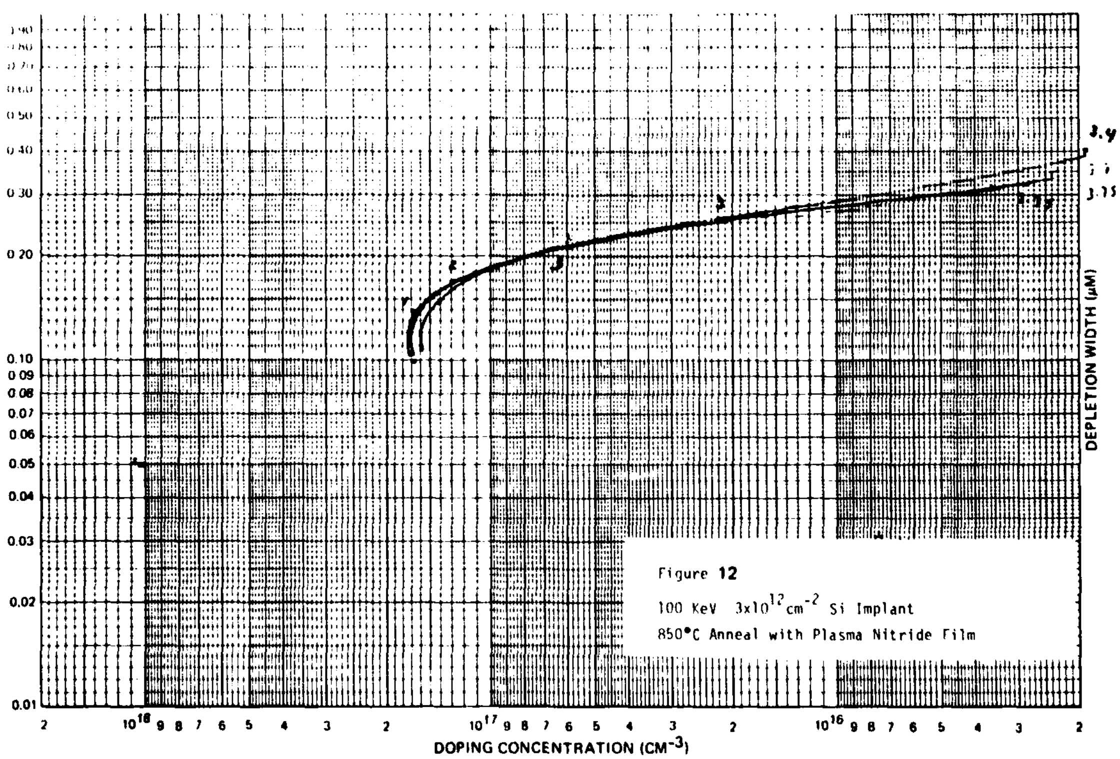


Figure 12

100 KeV $3 \times 10^{12} cm^{-2}$ Si Implant

850°C Anneal with Plasma Nitride Film

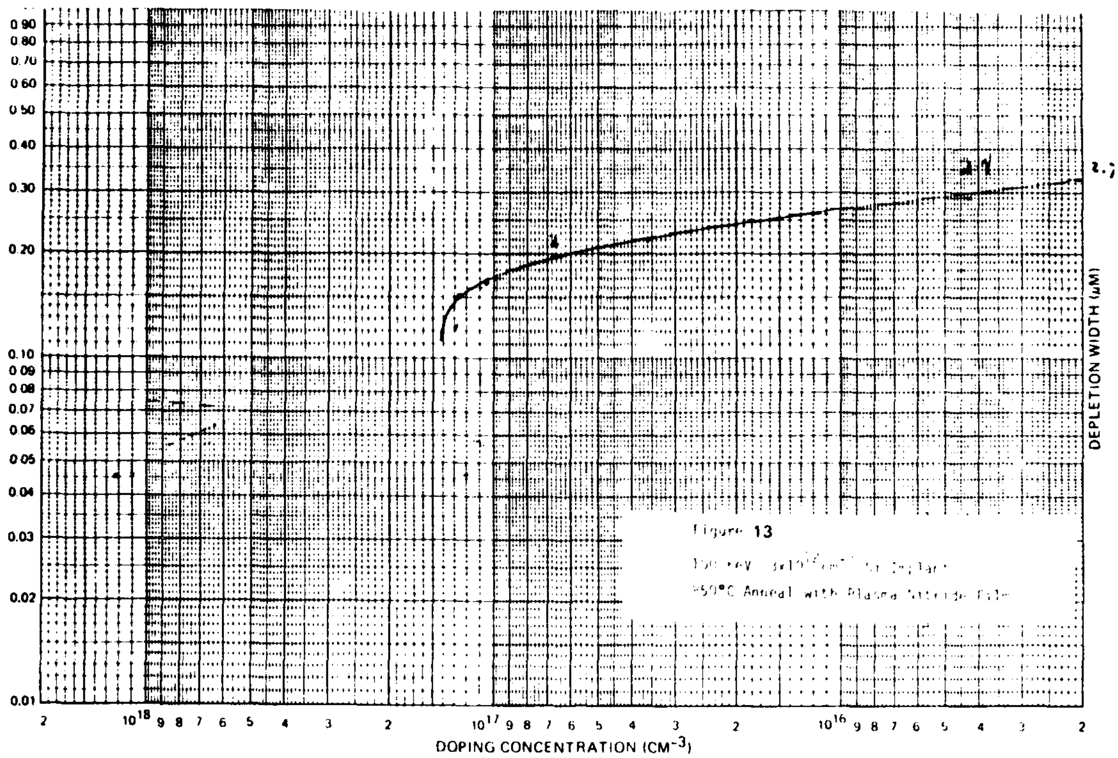


Figure 13
150 KeV $3x10^{12} cm^{-2}$ Si Implant
850°C Anneal with Plasma Nitride Film

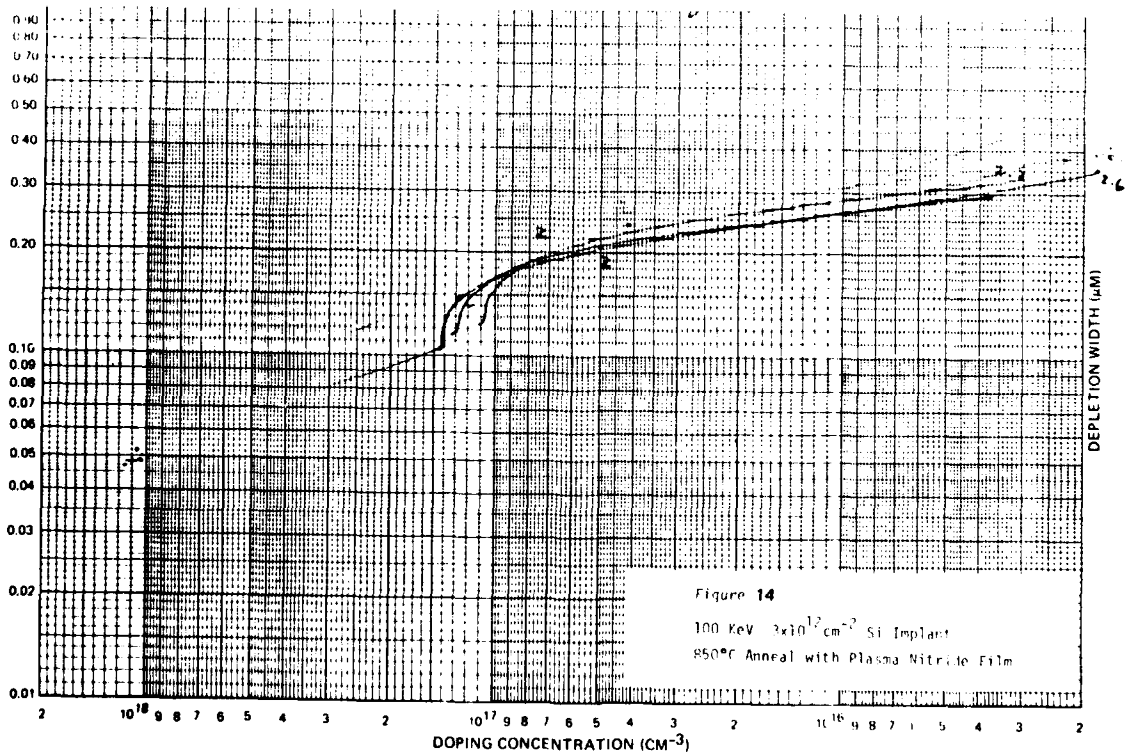


Figure 14
100 KeV $3x10^{12} cm^{-2}$ Si Implant
850°C Anneal with Plasma Nitride Film

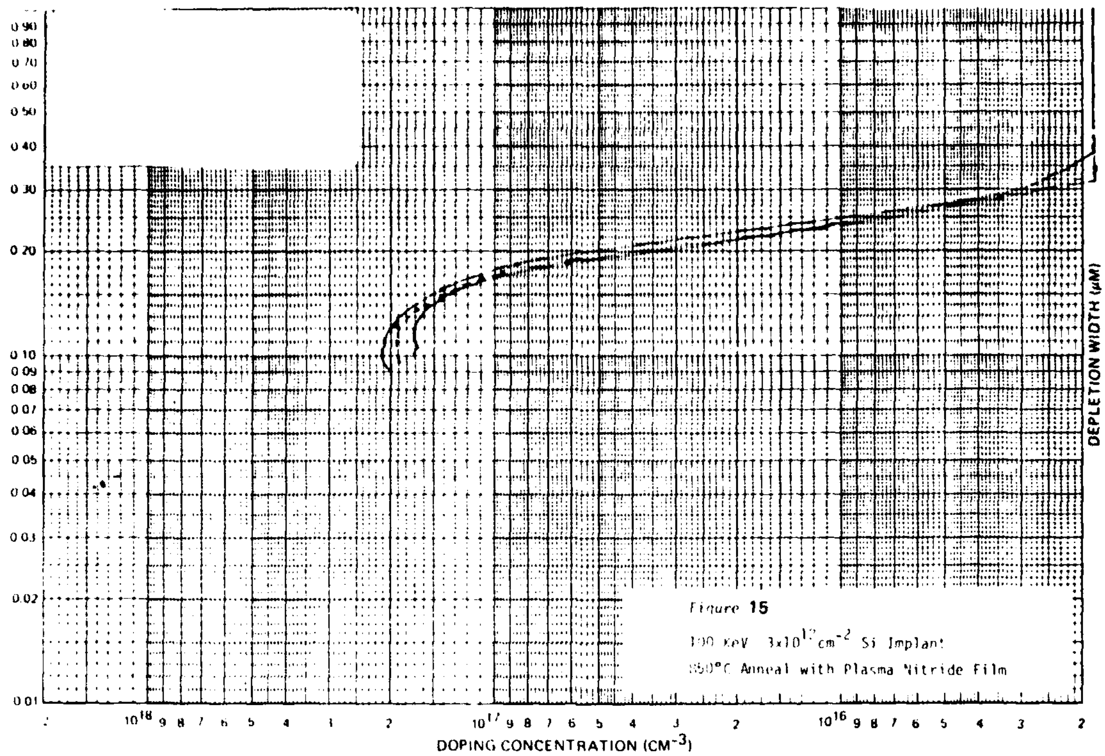


Figure 15

100 KeV $3x10^{12} cm^{-2}$ Si Implant

850°C Anneal with Plasma Nitride Film

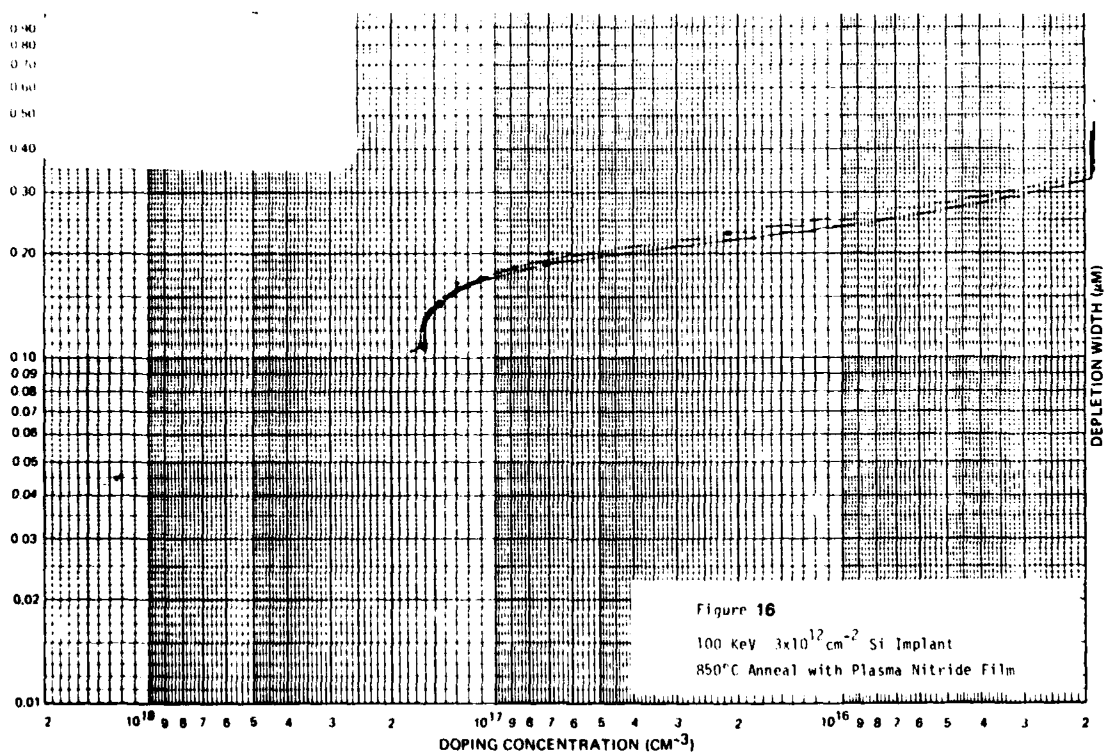


Figure 16

100 KeV $3x10^{12} cm^{-2}$ Si Implant

850°C Anneal with Plasma Nitride Film

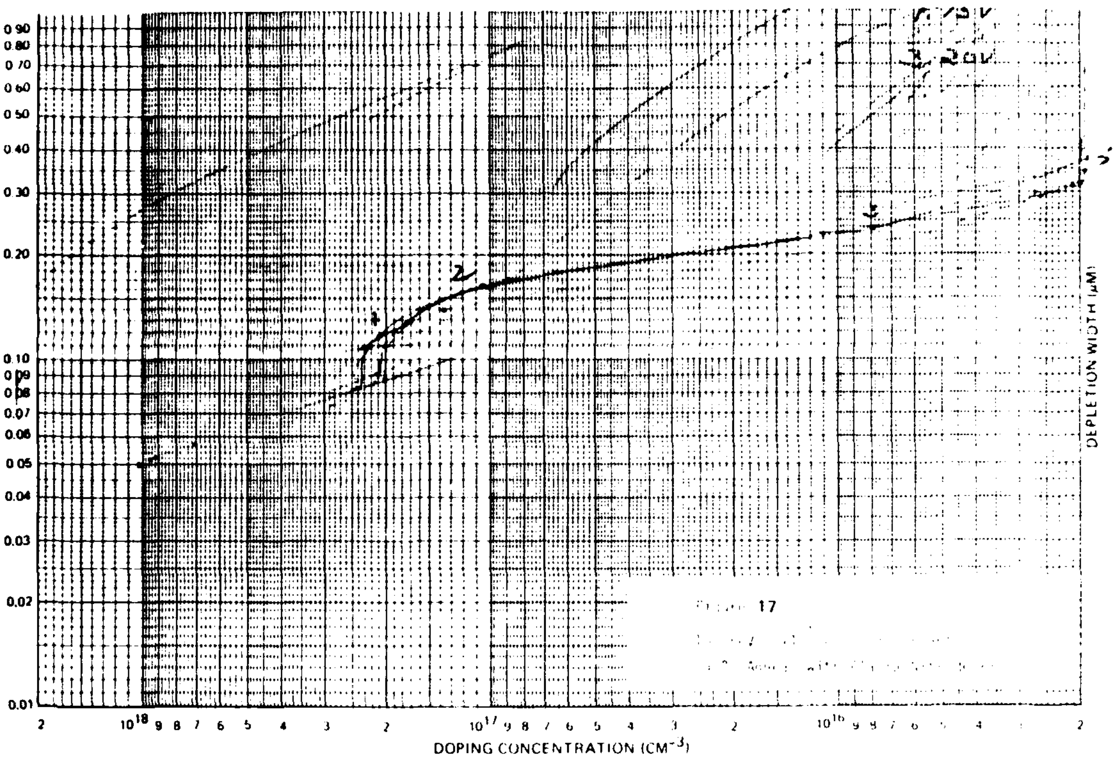


Figure 17

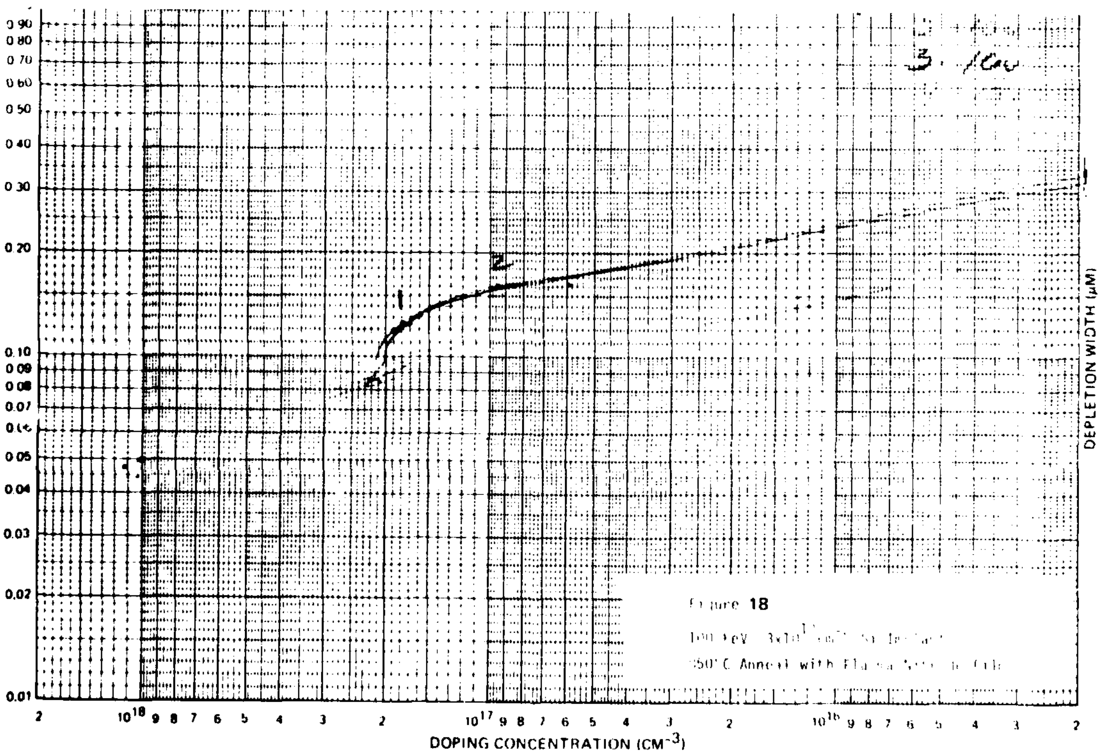


Figure 18

100 keV 3x10 ... Anneal with ...

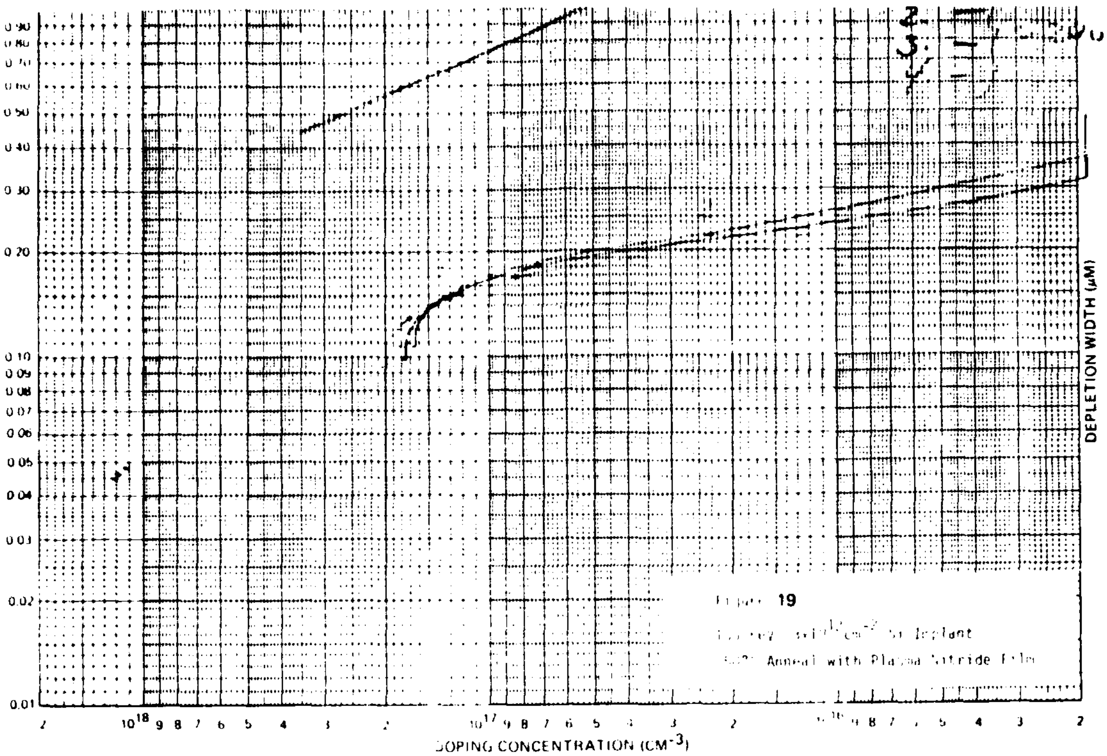


Figure 19

[illegible] KeV [illegible]$x10^{12}$ cm^{-2} Si Implant

[illegible] Anneal with Plasma Nitride Film

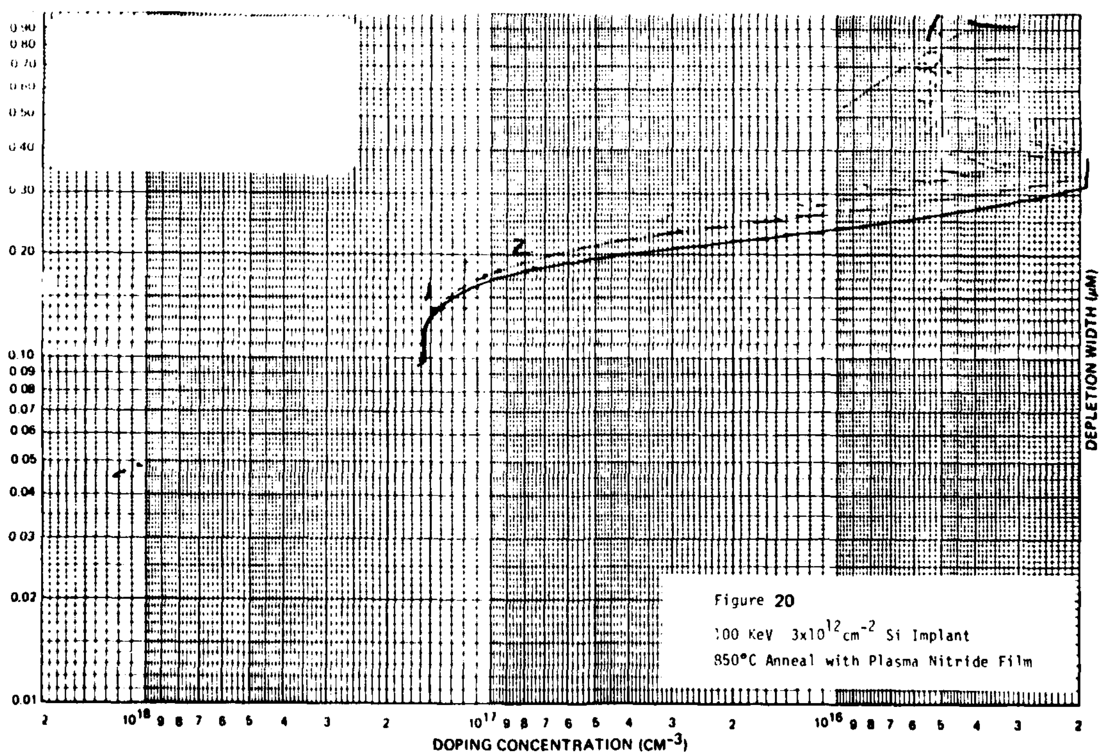
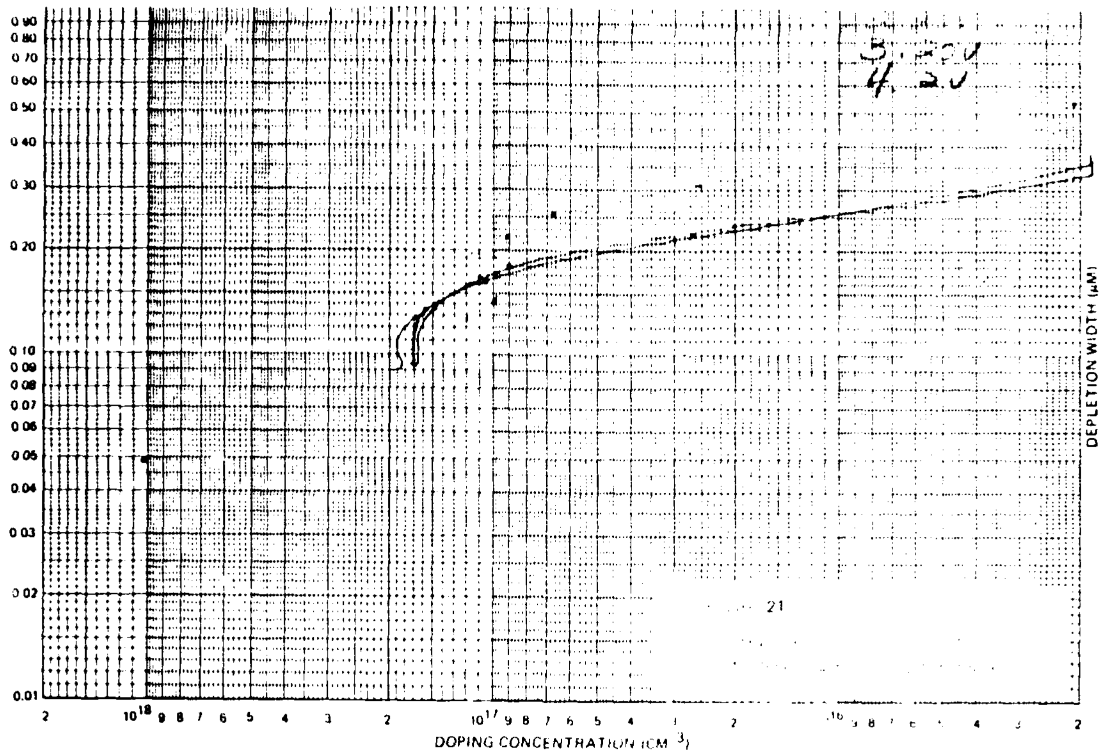
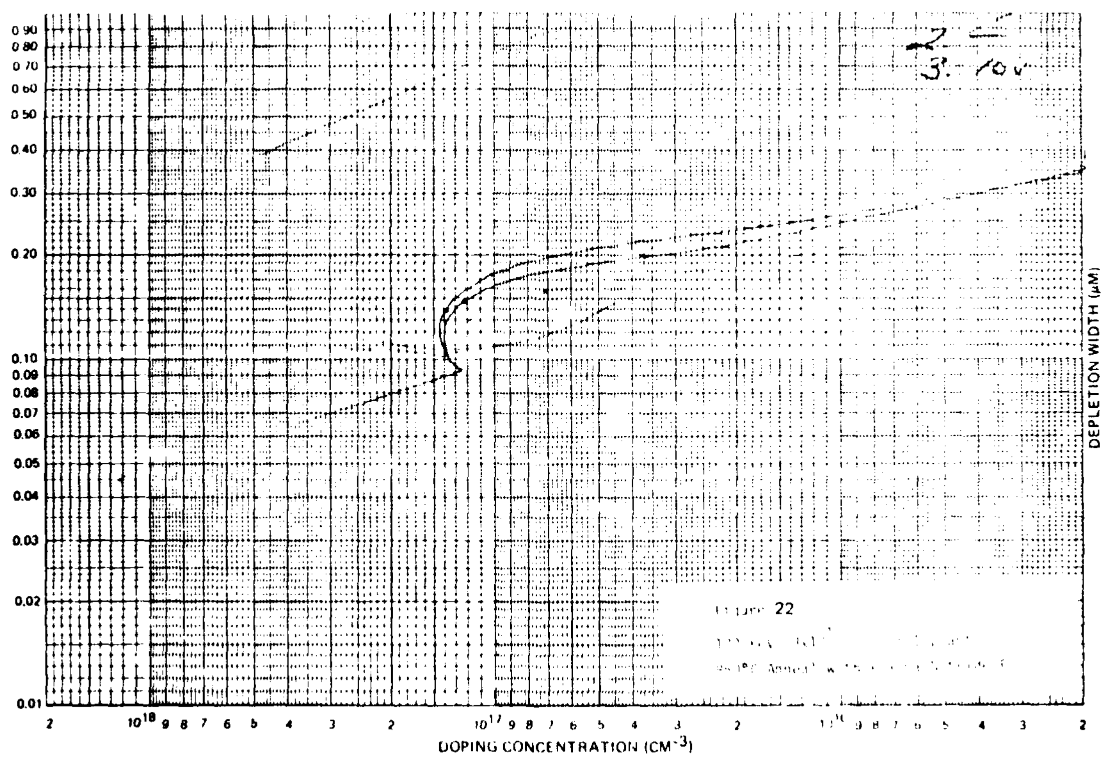


Figure 20

100 KeV $3x10^{12}$ cm^{-2} Si Implant

850°C Anneal with Plasma Nitride Film


5. 20V
4. 30
21
DEPLETION WIDTH (μM)
DOPING CONCENTRATION (CM-3)


2.
3. 10V
Figure 22
DEPLETION WIDTH (μM)
DOPING CONCENTRATION (CM-3)

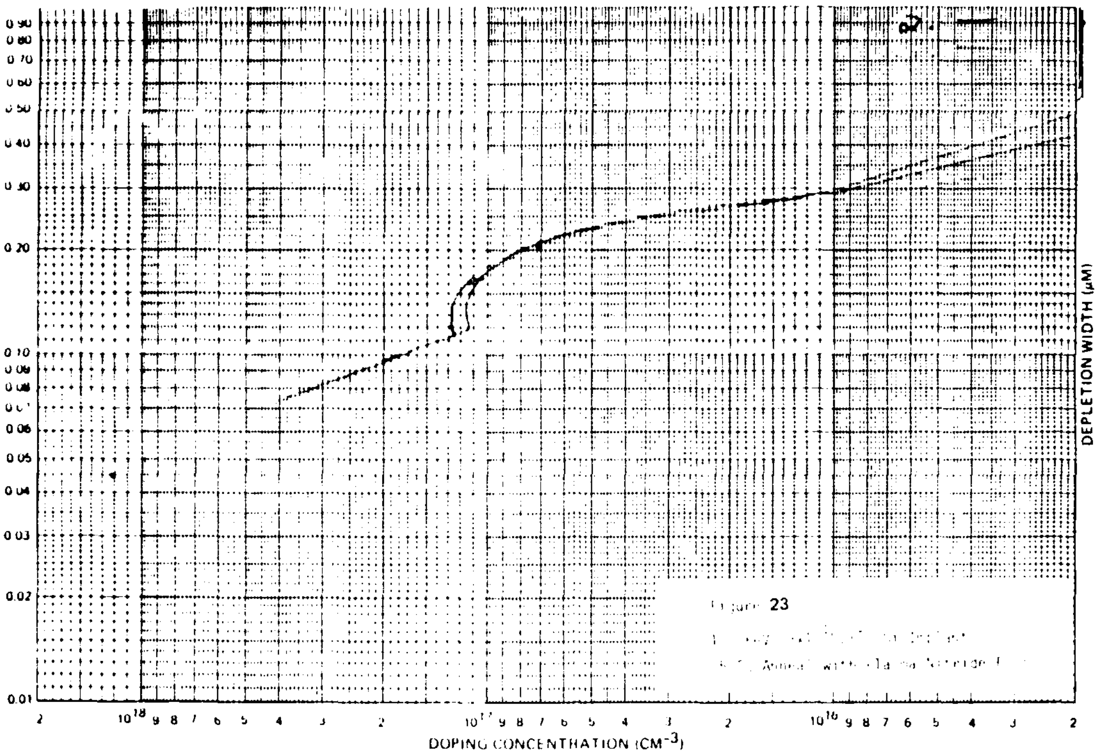


Figure 23

[illegible]

[illegible] Anneal with [illegible]

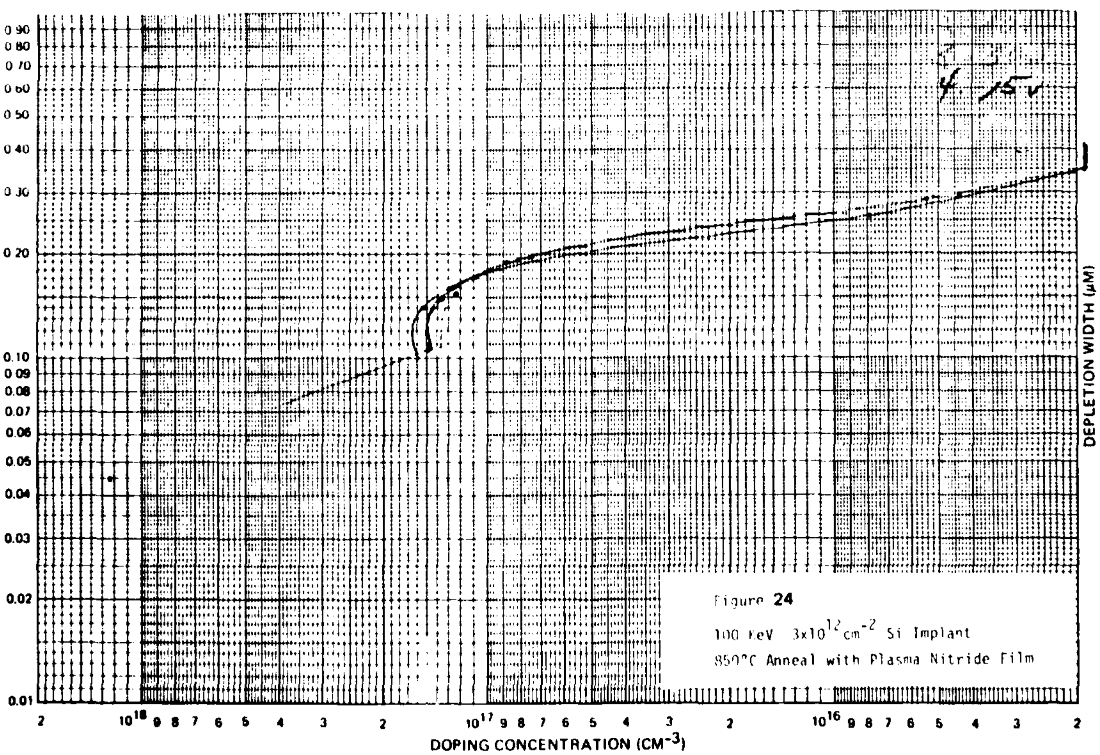
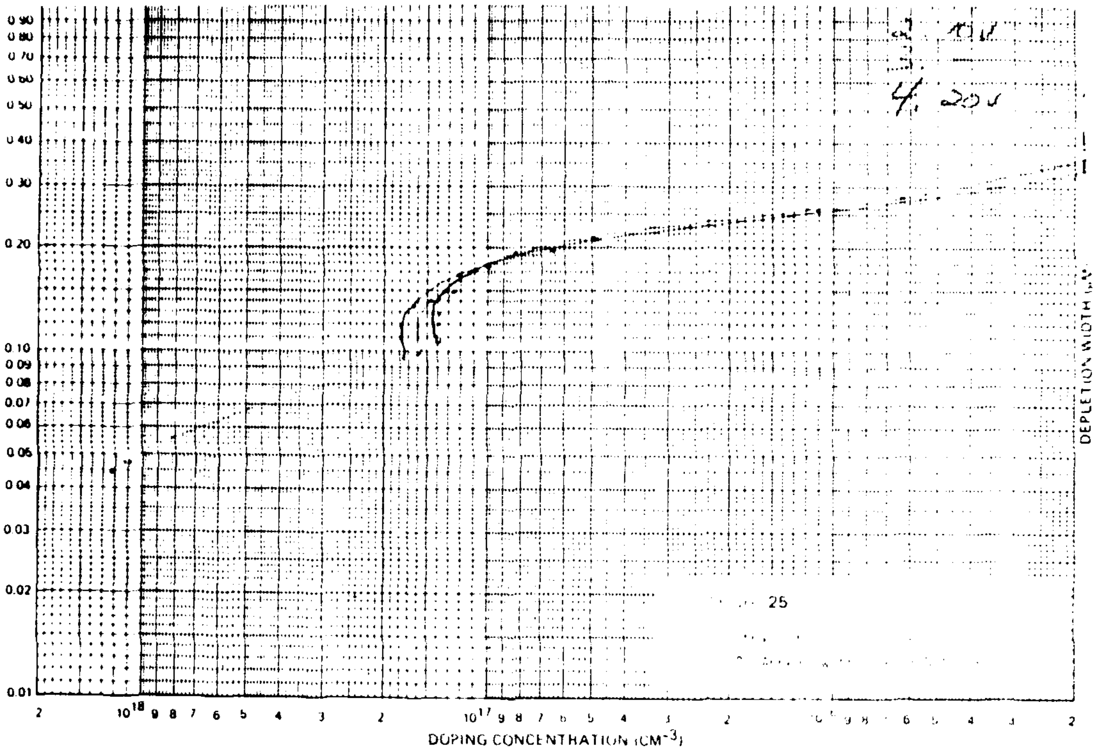


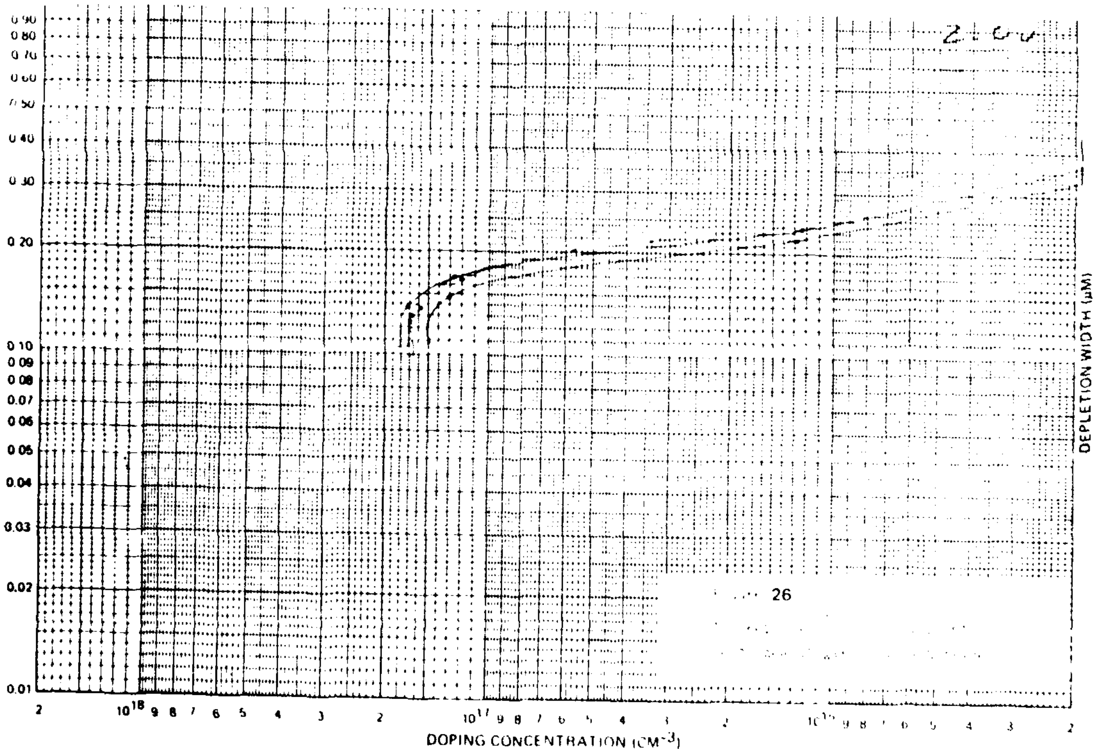
Figure 24

100 keV $3x10^{12} cm^{-2}$ Si Implant

850°C Anneal with Plasma Nitride Film



DEPLETION WIDTH
DOPING CONCENTRATION (CM⁻³)
25



DEPLETION WIDTH (μM)
DOPING CONCENTRATION (CM⁻³)
26

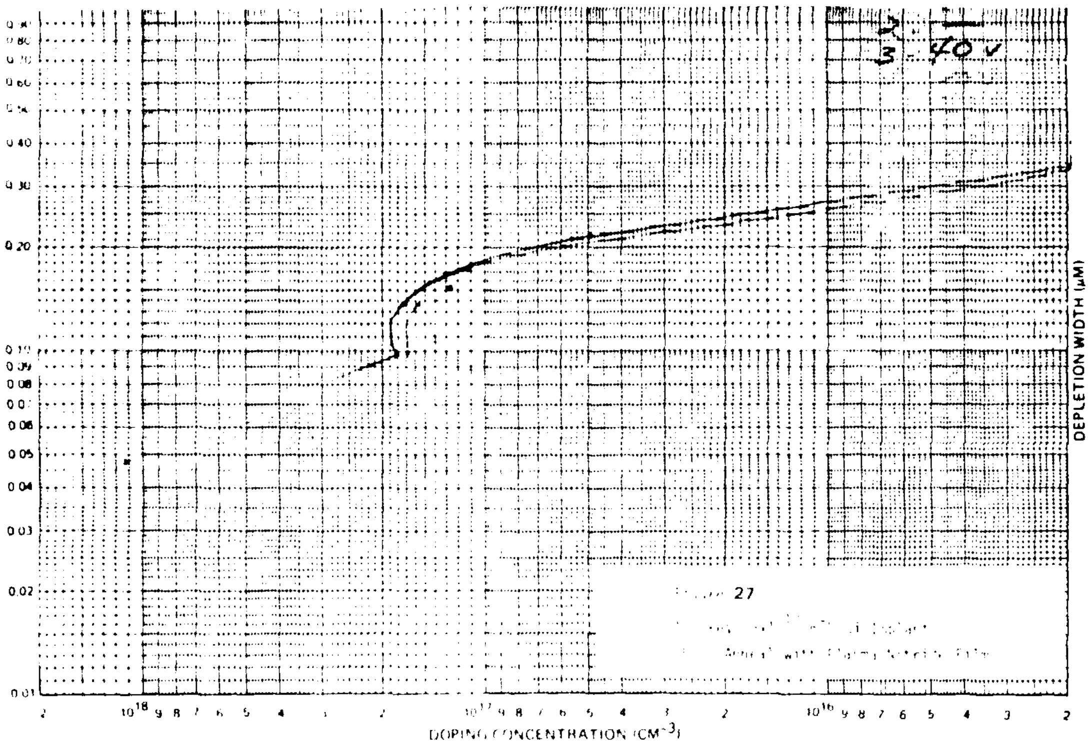


Figure 27

Annealed with Plasma Nitride Film

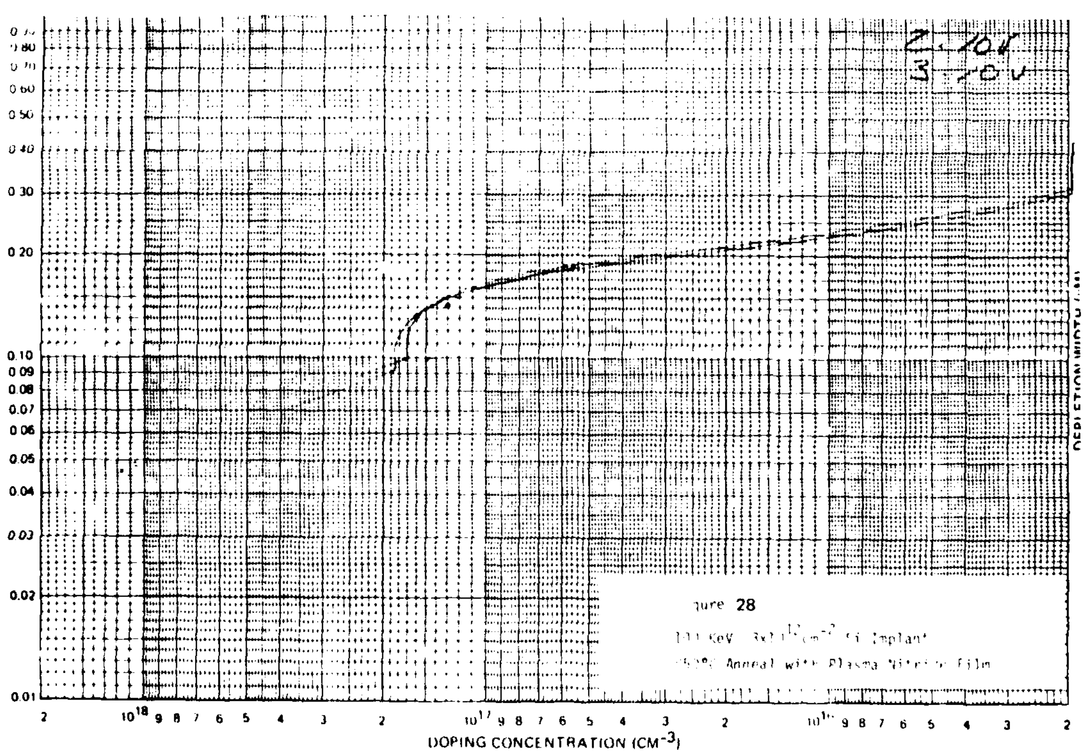


Figure 28

KeV Implant

Anneal with Plasma Nitride Film

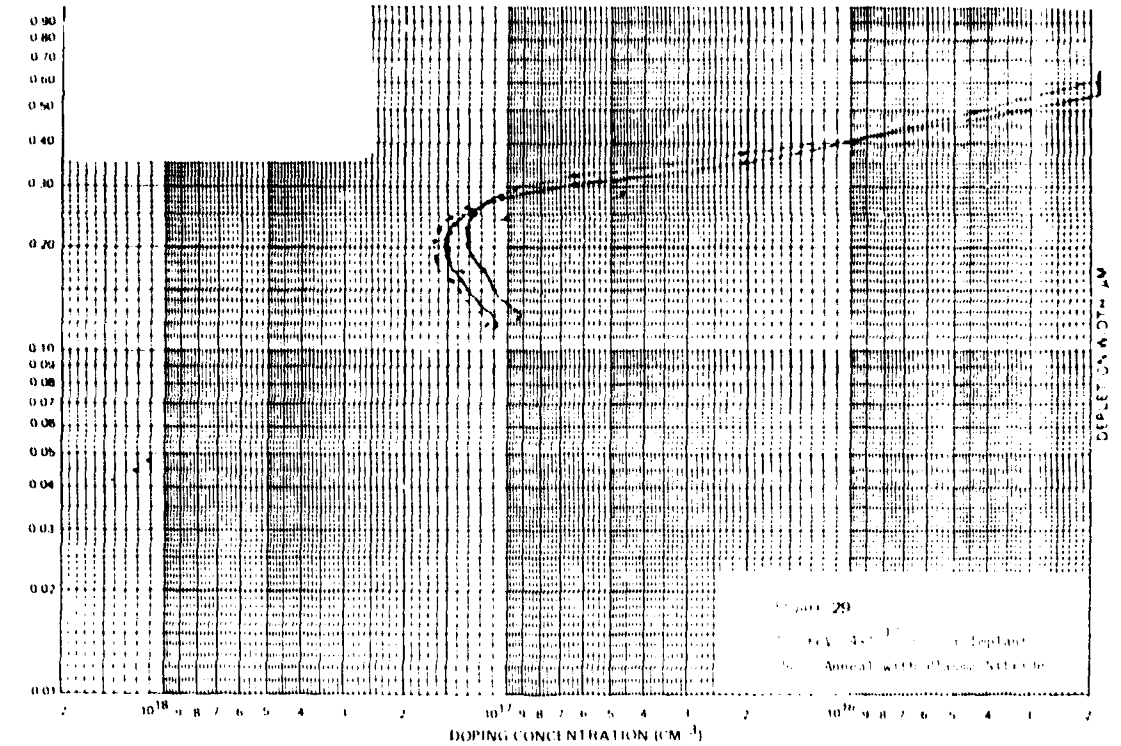


Figure 29

keV 4x[illegible] [illegible] Implant

[illegible] Anneal with Plasma Nitride

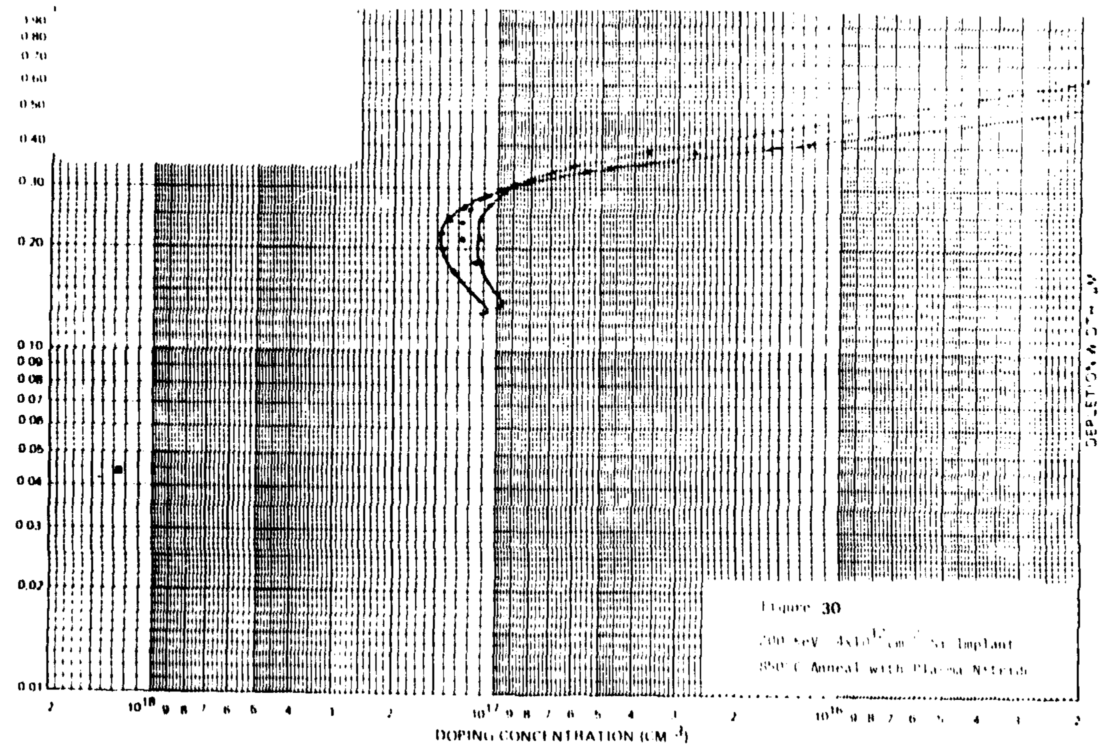


Figure 30

200 keV $4\times10^{12}\,cm^{-2}$ Si Implant

850°C Anneal with Plasma Nitride

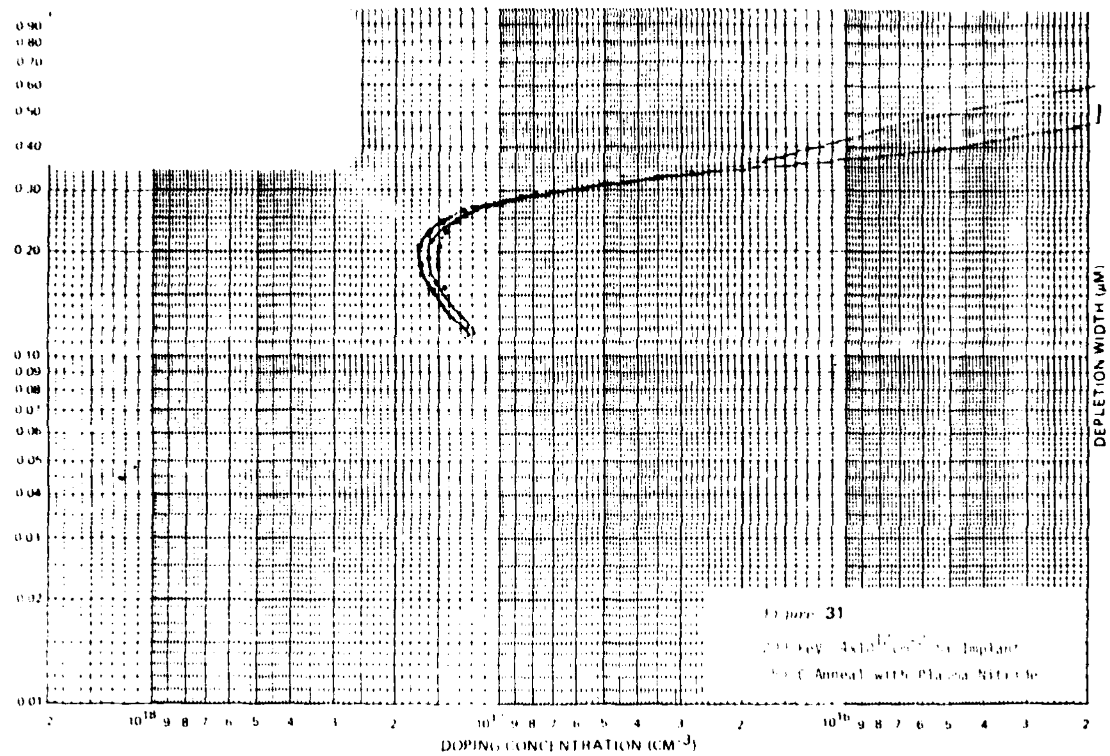


Figure 31

[illegible] keV 4×10^{12} cm^{-2} Si Implant

[illegible]°C Anneal with Plasma Nitride

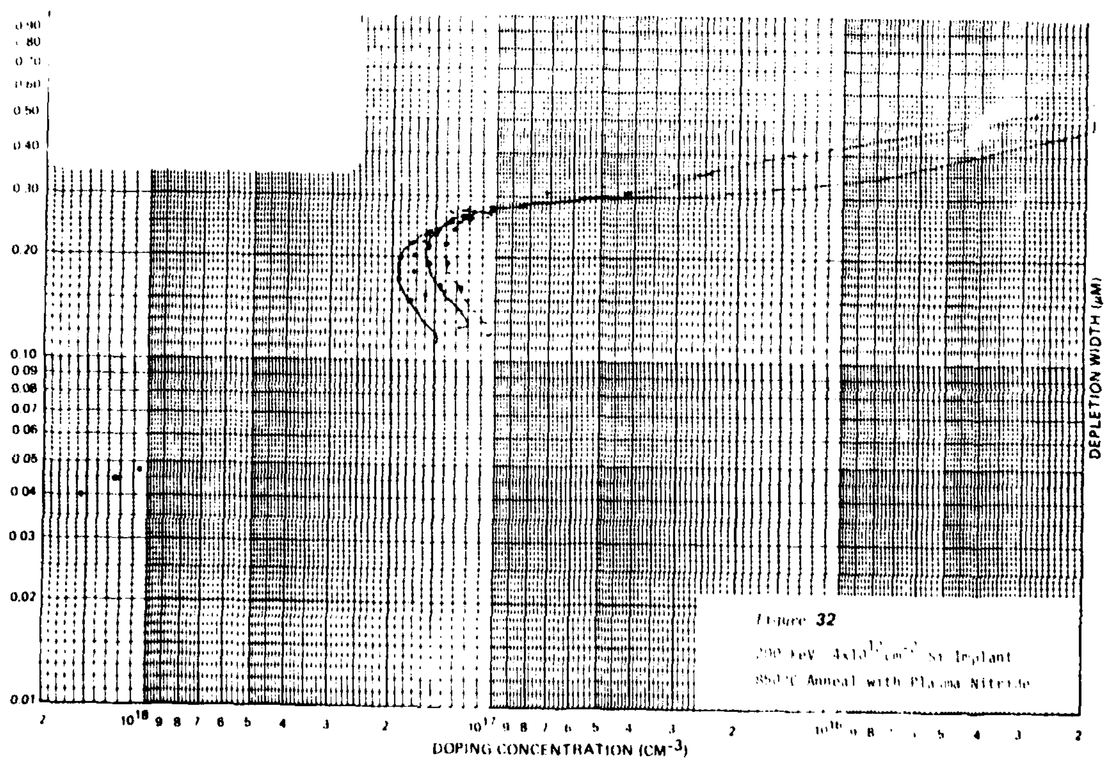


Figure 32

200 keV 4×10^{12} cm^{-2} Si Implant

850°C Anneal with Plasma Nitride

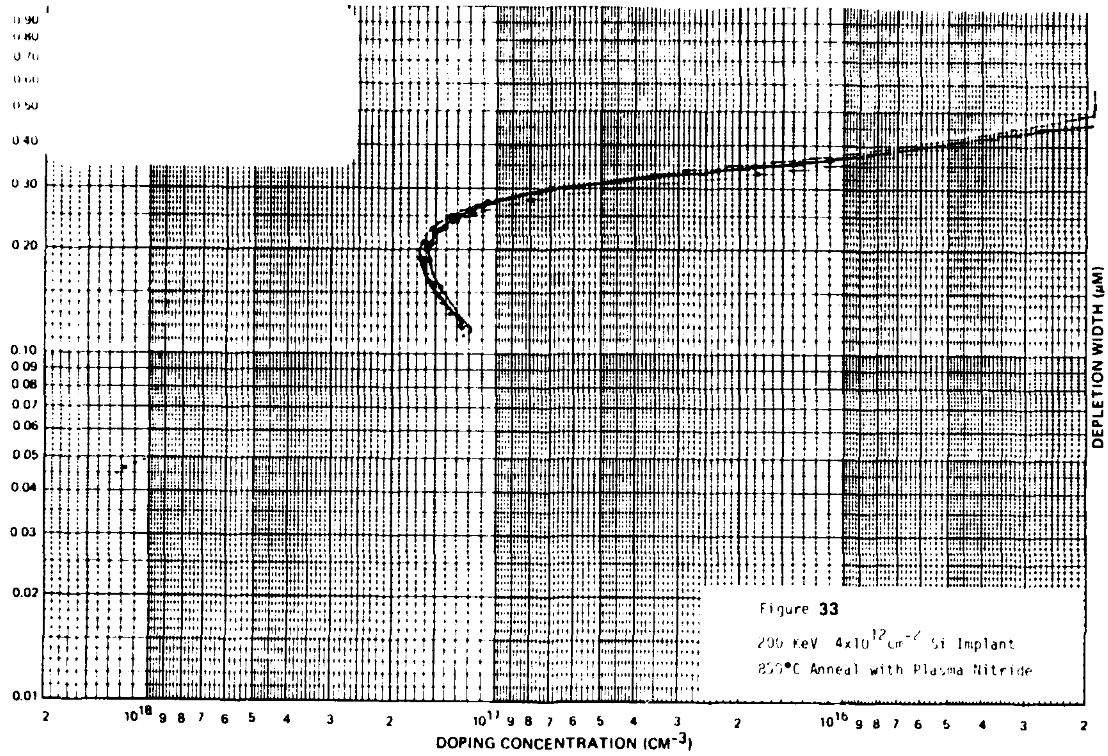


Figure 33
200 KeV $4x10^{12}cm^{-2}$ Si Implant
850°C Anneal with Plasma Nitride

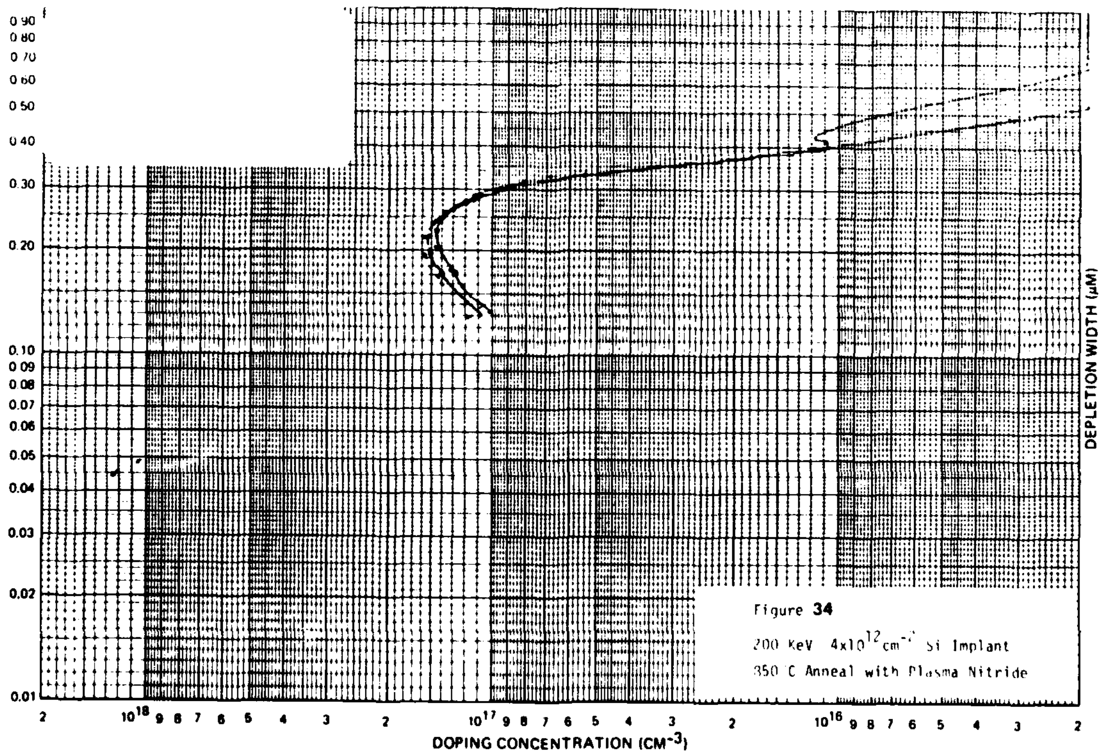


Figure 34
200 KeV $4x10^{12}cm^{-2}$ Si Implant
850°C Anneal with Plasma Nitride

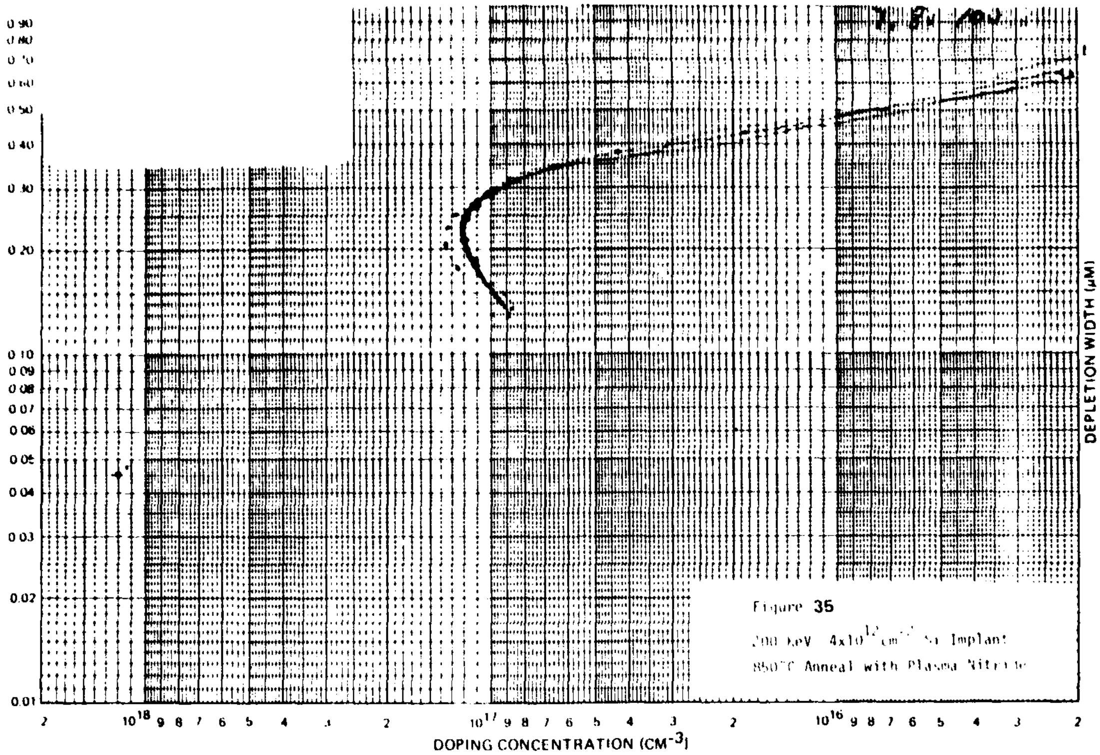


Figure 35
200 keV $4x10^{12}cm^{-2}$ Si Implant
850°C Anneal with Plasma Nitride

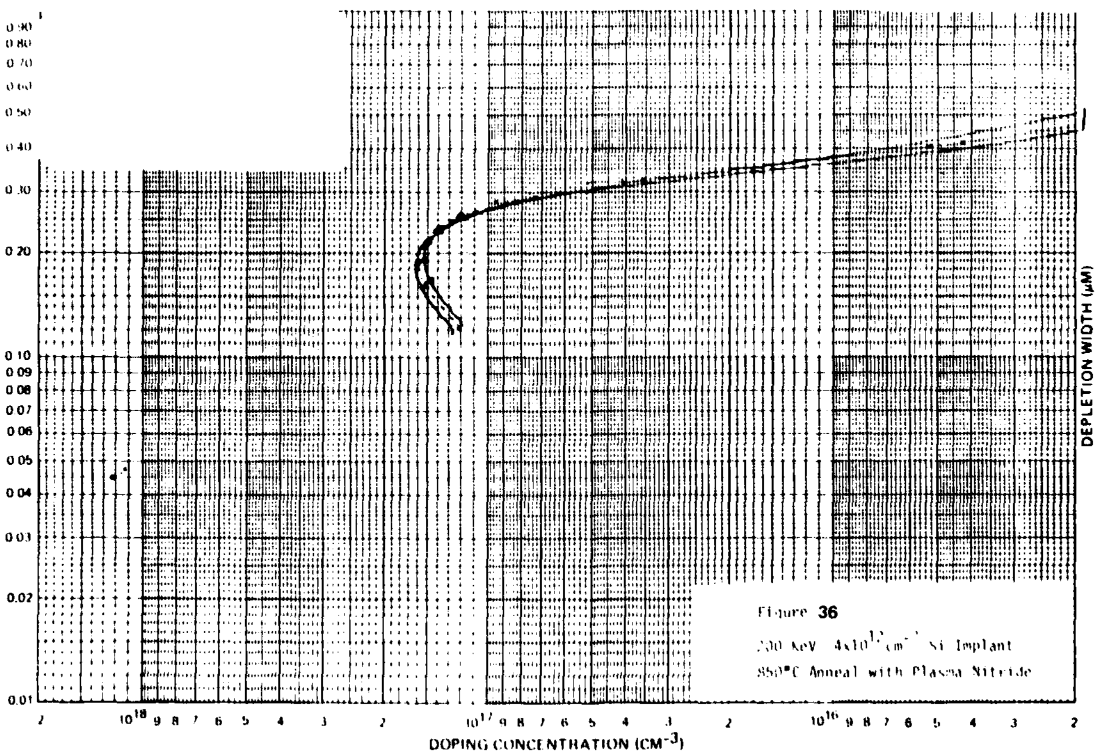


Figure 36
230 keV $4x10^{12}cm^{-2}$ Si Implant
850°C Anneal with Plasma Nitride

APPENDIX D

SUPPORTING ANALYSIS AND DATA FOR THE ANALOG MULTIPLIER DESIGNS

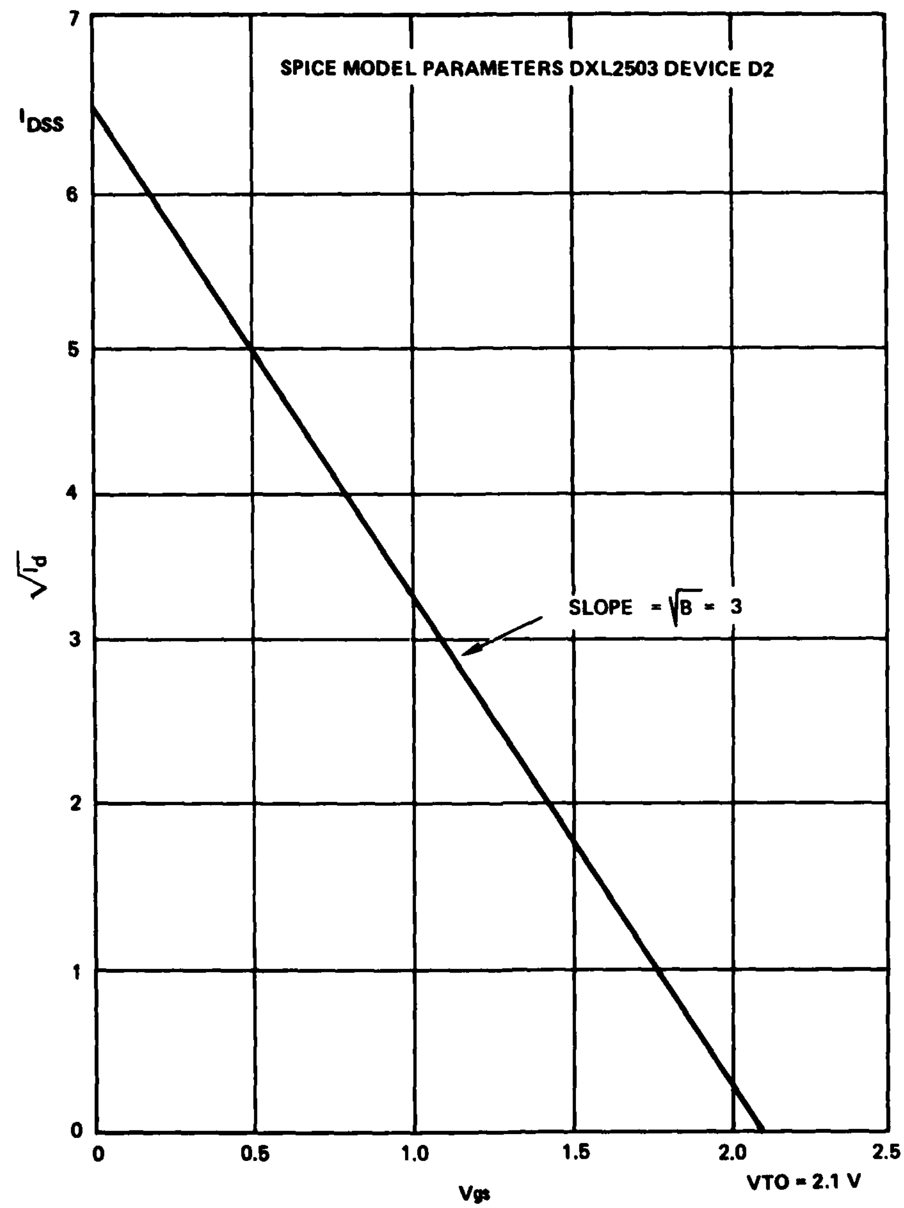


Figure 1. Spice Parameters for Device D2

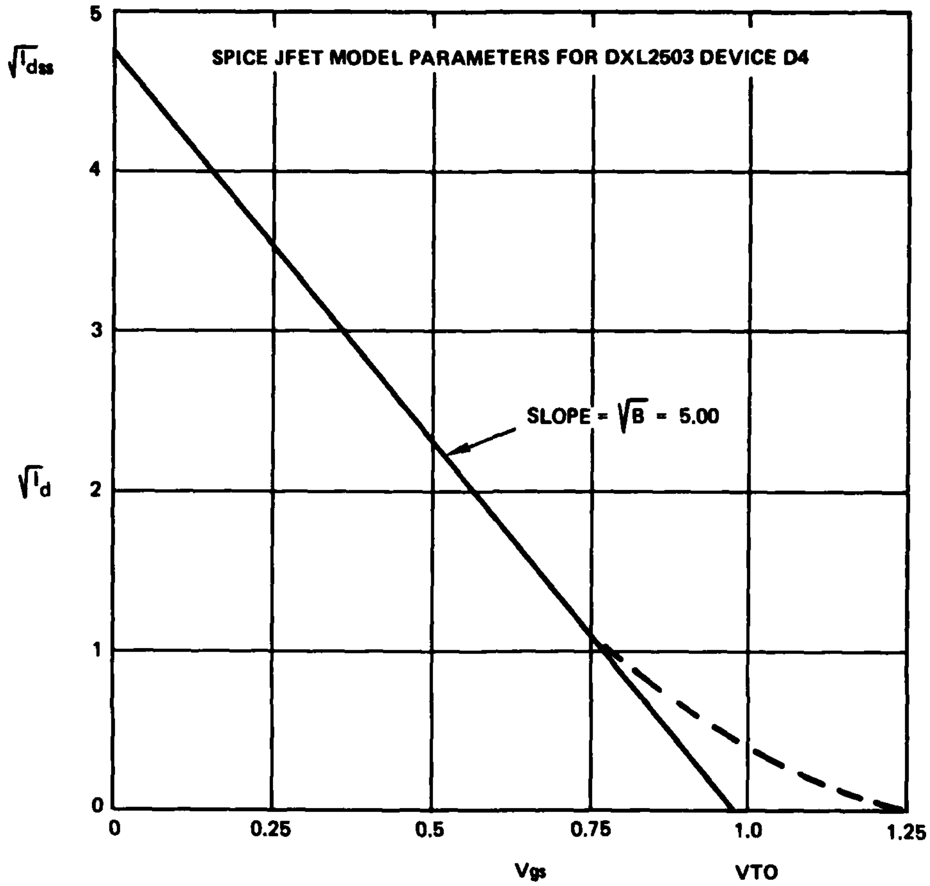


Figure 2. Spice Parameters for Device D4

The purpose of the appendix is to show that the drain to source voltage of transistor Q_5 (and Q_6) is 1/3 the differential voltage $\frac{A}{2} - \frac{\overline{A}}{2}$.

Figure 3 is a redrawing of the basic differential amplifier stage shown in Figure 5-15. Figure 4 is the equivalent differential mode half circuit about the x-x' axis of symmetry.

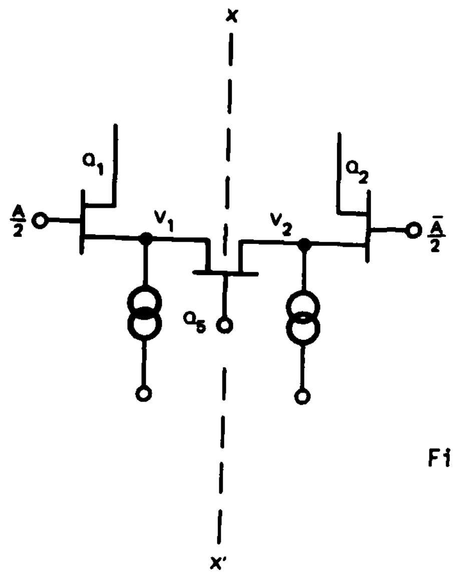


Figure 3. FET Differential Pair

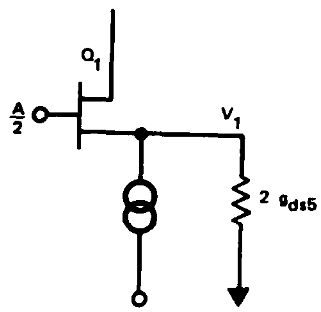


Figure 4. Model of the FET Half-Pair

Solving for V_{ds5}

$$V_{ds5} = V_1 - V_2 \tag{1}$$

$$V_1 = \left[\frac{g_{m1}}{g_{m1} + 2g_{ds5}}\right] A/2 \tag{2}$$

$$V_2 = \left[\frac{g_{m2}}{g_{m2} + 2g_{ds5}}\right] A/2 \tag{3}$$

If it can be shown that

$$g_{m1} = g_{m2} = \text{average value of } g_{ds5} \tag{4}$$

then substituting (4) into (2) and (3)

$$V_1 = 1/3\ A/2 \tag{5}$$

$$V_2 = 1/3\ \bar{A}/2 \tag{6}$$

$$V_{ds5} = V_1 - V_2 = 1/3\,\frac{A}{2} - 1/3\,\frac{\bar{A}}{2} = 1/3\ A \tag{7}$$

It is only left to show that (4) is correct under certain conditions. These conditions are that Q_1, Q_2, and Q_5 must have identical geometries and doping levels, and that Q_5 be driven by a perfectly symmetrical sinewave.

Using the data taken from DXL2503 device, the following table shows that for a given gate voltage, g_m and g_{ds} are approximately equal.

V_g	g_m	g_{ds}
0	35	40
0.5	30	34
1.0	15	17
1.5	2.6	6

If all gates are dc grounded and the current sources are adjusted such that the source of Q1 and Q2 is at 1 volt, then notice that the source of Q5 is at 1 volt. Therefore, $V_{GS1} = V_{GS2} = V_{GS5}$ and $g_{m1} = g_{m2} \approx g_{ds5}$. When signals are applied, V_{gs1} and V_{gs2} change very little because the RF voltage is small; therefore, g_{m1} and g_{m2} remain constant. g_{ds5} varies sinusoidally at the LO rate from its dc value of 15 mmho up to its maximum value of $\approx$30 mmho down to a minimum of 0 mmho. It can clearly be seen that g_{ds5} average = 15 mmho, the dc value of g_{ds5}. Hence, $g_{m1} = g_{m2}$ = average value of g_{ds5}.

```
 TRW SPICE (01/15/79)          03/29/79. 14.55.02.

VARIABLE TRANSCONDUCTANCE MULTIPLIER

     INPUT LISTING                          TEMPERATURE =   27.000 DEG C

**************************************************************************

VDD 11 0 DC 9.0
VG1 1 0 DC 3
VG2 0 10 DC .50
VLO 9 8 SIN(0 .50 6GHZ)
VRF 2 3 SIN(0 .01 10GHZ)
R1 2 1 51
R2 3 1 51
R3 9 10 51
R4 8 10 51
RD1 11 4 250
RD2 11 6 250
J1 4 2 5 JDX2503
J2 6 3 5  JDX2503
J3 4 3 7 JDX2503
J4 6 2 7 JDX2503
J5 5 9 0 JDXL2503
J6 7 8 0 JDXL2503
.MODEL JDX2503 NJF(VTO=-1 BETA=11M CGS=.015P CGD=.04P RD=3.4 RS=2)
.MODEL JDXL2503 NJF(VTO=-1 BETA=22M CGS=.02P CGD=.06P RD=3.4 RS=2)
.FOUR 2GHZ V(4,6)
.TRAN .025NS 1.25NS
.PLOT TRAN V(4,6)
.END
```

TRW SPICE (01/15/79) 03/29/79. 14.55.03.

VARIABLE TRANSCONDUCTANCE MULTIPLIER

JFET MODEL PARAMETERS TEMPERATURE = 27.000 DEG C

****

	JDX2503	JDXL2503
TYPE	NJF	NJF
VTO	-1.000	-1.000
BETA	1.10E-02	2.20E-02
RD	3.400	3.400
RS	2.000	2.000
CGS	1.50E-14	2.00E-14
CGD	4.00E-14	6.00E-14

TRW SPICE (01/15/79)   03/29/79. 14.55.22.

VARIABLE TRANSCONDUCTANCE MULTIPLIER

INITIAL TRANSIENT SOLUTION   TEMPERATURE =   27.000 DEG C

****

NODE	VOLTAGE	NODE	VOLTAGE	NODE	VOLTAGE	NODE	VOLTAGE
(1)	3.0000	(2)	3.0000	(3)	3.0000	(4)	7.6824
(5)	3.5053	(6)	7.6824	(7)	3.5053	(8)	-.5000
(9)	-.5000	(10)	-.5000	(11)	9.0000		

VOLTAGE SOURCE CURRENTS

NAME	CURRENT
VDD	-1.054E-02
VG1	8.018E-12
VG2	-3.479E-12
VLO	1.110E-16
VRF	6.661E-16

TOTAL POWER DISSIPATION   9.49E-02 WATTS

TRW SPICE (01/15/79)   03/29/79. 14.55.22.

VARIABLE TRANSCONDUCTANCE MULTIPLIER

OPERATING POINT INFORMATION   TEMPERATURE = 27.000 DEG C

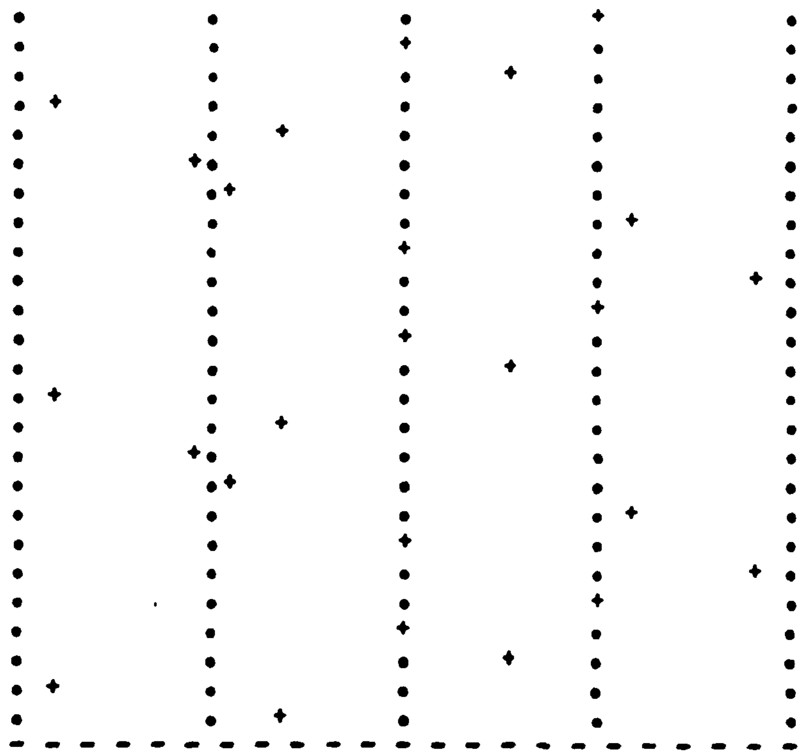
****

**** JFETS

	J1	J2	J3	J4	J5	J6
MODEL	JDX2503	JDX2503	JDX2503	JDX2503	JDXL2503	JDXL2503
ID	2.64E-03	2.64E-03	2.64E-03	2.64E-03	5.27E-03	5.27E-03
VGS	-.505	-.505	-.505	-.505	-.500	-.500
VDS	4.177	4.177	4.177	4.177	3.505	3.505

```
TRW SPICE (01/15/79)          03/29/79. 14.56.17.

VARIABLE TRANSCONDUCTANCE MULTIPLIER

    TRANSIENT ANALYSIS               TEMPERATURE =   27.000 DEG C

*****************************************************************

   TIME        V(4,6)

                        -2.000E-02 -1.000E-02  0.000     1.000E-02  2.000E-02
                         - - - - - - - - - - - - - - - - - - - - -
0.000        5.694E-14   .         .         +         .         .
2.500E-11   -1.073E-02   .        +.         .         .         .
5.000E-11   -9.465E-03   .         .+        .         .         .
7.500E-11    1.193E-02   .         .         .         . +       .
1.000E-10    2.130E-04   .         .         +         .         .
1.250E-10    1.810E-02   .         .         .         .       + .
1.500E-10    9.850E-03   .         .         .         +         .
1.750E-10   -3.830E-04   .         .         +         .         .
2.000E-10    5.669E-03   .         .         .    +    .         .
2.250E-10   -1.863E-02   . +       .         .         .         .
2.500E-10   -6.273E-03   .         .   +     .         .         .
2.750E-10   -1.104E-02   .        +.         .         .         .
3.000E-10   -9.455E-03   .         .+        .         .         .
3.250E-10    1.193E-02   .         .         .         . +       .
3.500E-10    2.259E-04   .         .         +         .         .
3.750E-10    1.809E-02   .         .         .         .       + .
4.000E-10    9.816E-03   .         .         .         +         .
4.250E-10   -3.769E-04   .         .         +         .         .
4.500E-10    5.680E-03   .         .         .    +    .         .
4.750E-10   -1.862E-02   . +       .         .         .         .
5.000E-10   -6.241E-03   .         .   +     .         .         .
5.250E-10   -1.104E-02   .        +.         .         .         .
5.500E-10   -9.481E-03   .         .+        .         .         .
5.750E-10    1.193E-02   .         .         .         . +       .
6.000E-10    2.130E-04   .         .         +         .         .
6.250E-10    1.810E-02   .         .         .         .       + .
```

6.500E-10	9.850E-03
6.750E-10	-3.830E-04
7.000E-10	5.669E-03
7.250E-10	-1.863E-02
7.500E-10	-6.273E-03
7.750E-10	-1.104E-02
8.000E-10	-9.455E-03
8.250E-10	1.193E-02
8.500E-10	2.259E-04
8.750E-10	1.809E-02
9.000E-10	9.816E-03
9.250E-10	-3.769E-04
9.500E-10	5.680E-03
9.750E-10	-1.862E-02
1.000E-09	-6.241E-03
1.025E-09	-1.104E-02
1.050E-09	-9.481E-03
1.075E-09	1.193E-02
1.100E-09	2.130E-04
1.125E-09	1.810E-02
1.150E-09	9.850E-03
1.175E-09	-3.830E-04
1.200E-09	5.669E-03
1.225E-09	-1.863E-02
1.250E-09	-6.225E-03



TRW SPICE (01/15/79)   03/29/79. 14.56.21.

VARIABLE TRANSCONDUCTANCE MULTIPLIER

FOURIER ANALYSIS   TEMPERATURE =   27.000 DEG C

****

FOURIER COMPONENTS OF TRANSIENT RESPONSE V(4,6)

DC COMPONENT =   1.502E-07

HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	2.000E+09	5.764E-07	1.000000	-27.465	0.000
2	4.000E+09	1.227E-02	21294.137118	-93.638	-66.173
3	6.000E+09	8.930E-07	1.549167	125.099	152.564
4	8.000E+09	1.096E-04	190.127504	-66.226	-38.761
5	1.000E+10	2.331E-07	.404380	-130.984	-103.519
6	1.200E+10	4.579E-07	.794341	-138.554	-111.089
7	1.400E+10	6.836E-07	1.185952	114.520	141.985
8	1.600E+10	9.420E-03	16342.157404	39.714	67.179
9	1.800E+10	5.178E-07	.898224	73.242	100.707

TOTAL HARMONIC DISTORTION = ************* PERCENT

JOB CONCLUDED